AD NUMBER
AD892861
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; 22 FEB 1972. Other requests shall be referred to Office of Naval Research, Arlington, VA 22203.**
AUTHORITY
ONR ltr 29 Aug 1973

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

ORIGINATING ACTIVITY (Corporate author)
Stanford Research Institute

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

REPORT TITLE
SYSTEMS ANALYSIS OF AMPHIBIOUS LANDING CRAFT: A COMPARISON OF LANDING CRAFT AND HELICOPTER PERFORMANCE IN AMPHIBIOUS ASSAULTS

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)
MS Research Memorandum

5 AUTHOR(S) (First name, middle initial, last name)
Andrew R. Grant

REPORT DATE
November 1971

7a. TOTAL NO. OF PAGES
108

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO. N00014-71-C-0390

b. PROJECT NO. S 14.17

c. NR274-008-19

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
NWRC/MSD-RM-60

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Distribution limited to U.S. Government agencies only (test and evaluation: 22 February 1972). Other requests for this document must be referred to the Office of Naval Research (Code 462).

11 SUPPLEMENTARY NOTES
Naval Analysis Programs (Code 462)
Office of Naval Research
Arlington, Virginia 22217

12. SPONSORING MILITARY ACTIVITY
Naval Ships Systems Command and Naval Analysis Programs
Office of Naval Research
Washington, D.C.

13 ABSTRACT

This report compares the relative performance of helicopters and landing craft in amphibious assault operations, based on the results of a number of detailed simulations of amphibious operations using various combinations of ships, helicopters, landing craft and operating modes in the mid-range time period (to 1985).

Two different forces were used in the analysis--one a Marine Amphibious Force (MAF) including all its usual heavy vehicles and equipment, and the other a specially devised helicopter-liftable force (HLF) of lower strength and lighter equipment.

A principal conclusion of the report is that operations using both helicopters and landing craft as delivery vehicles are more effective than those in which only helicopters or only landing craft are used. The large air cushion landing craft (the C150) appears the most effective delivery vehicle.

A description of the GAMUT model is included.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Landing Craft						
Advanced Landing Craft						
Helicopter						
Air Cushion Vehicle						
Marine Amphibious Force						
MAF						
Helicopter Liftable Force						
HLF						
Amphibious Assault						
Simulation						
GAMUT						
Cost Effectiveness						
Force-time Effectiveness						
Productivity						
Delivery Rates						
Cycle Times						

NWRC/MSD-RM-60

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11, 32, 34, 40, 33

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Prepared for:

NAVAL SHIPS SYSTEMS COMMAND AND
NAVAL ANALYSIS PROGRAMS, OFFICE OF NAVAL RESEARCH
WASHINGTON, D.C.

CONTRACT N00014-71-C-0390
Task NR 274-008-19

STANFORD RESEARCH INSTITUTE
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SRI Project MSU-1291

PREFACE

This memorandum report describes a specialized part of the Systems Analysis of Amphibious Landing Craft, which is in turn part of the Navy's Amphibious Assault Landing Craft (AALC) Program (S14-17X). The subject addressed here is the competitive and complementary roles played by landing craft and helicopters in amphibious assault environments where each is assigned delivery tasks for troops, vehicles, equipment, and cargo. The report also discusses the interface between landing craft and helicopters. The measures of effectiveness used in this report were selected to permit objective comparisons between the performance of mixes of landing craft and mixes of helicopters. For the benefit of the reader who is not familiar with the AALC program, brief summaries of previous SRI studies are given in Appendix A.

To assure full consideration of helicopter potential, the results of the analysis reflect a level of helicopter operations that is near the upper limit of present and planned helicopter capability. Landing craft performance, cost, and operation data are based on the best information available from the AALC program.

The work described in this report was performed by the technical staff of SRI's Transportation and Distribution Systems Department. Technical direction of this work is provided by Mr. James L. Schuler, NavShips Program Manager, and Mr. M. W. Brown, NSRDC Code 118, Technical Manager of the Navy's Amphibious Assault Landing Craft Program. Dr. Paul S. Jones of SRI is Program Manager of the Systems Analysis of Amphibious Landing Craft. Mr. Andrew R. Grant is Project Leader. Administrative direction of SRI's work is provided by Mr. R. J. Miller, Director, Naval Analysis Programs, Office of Naval Research, through the Institute's Naval Warfare Research Center.

The major portion of the data used in this analysis was obtained through use of SRI's GAMUT program, written by A. R. Grant and J. I. Steinman. Mr. Grant was principal investigator for this work. Mr. Steinman provided technical help and contributed the section on Scope. P. S. Jones provided technical direction and review.

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I INTRODUCTION AND SUMMARY

The objective of the Navy's Amphibious Assault Landing Craft Program (S14-17X) is to provide the design and development work needed to specify a new family of amphibious landing craft that is significantly more cost-effective and operationally flexible than the family of landing craft now in service. Thus, the primary focus of the program is on landing craft, surface assault, and landing-craft support systems. However, the surface assault problem must not be studied in isolation lest the program seek to optimize surface assault at the expense of other vital activities. In particular, the complementary roles of air and surface assault need to be borne continuously in mind.

This report describes the results of a study of the complementary roles of landing craft and helicopters when delivering ashore all of the assault and support elements of two different types of forces. The two forces are a conventional Marine Amphibious Force (MAF)* and a division-size, helicopter-liftable force (HLF) especially designed for this work. The principal characteristics of both forces are summarized in Appendix B. The work described here has considered delivery of personnel, vehicles, equipment and cargo to amphibious objectives areas by a fleet of ships including LPH, LPD, LHA, LKA, LST and LSD, followed by a ship-to-shore assault using LVTs, landing craft, helicopters, and LSTs in various mixes.

Objective

The objective of this study has been to compare the performance of mixes of helicopters and landing craft in support of amphibious assaults; to identify the relative strengths of each delivery means; and to suggest complementary roles that each type of delivery vehicle might fill in future amphibious assaults.

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* See Means, E. H. and D. E. Vaughn, "Marine Assault Forces and Amphibious Operation Plans (U)," NWRC/LSR-RM42, Stanford Research Institute, Menlo Park, California, August 1967 (CONFIDENTIAL).

Scope

The relative performance of landing craft and helicopters depends on the type and number of each that are carried to the amphibious objective area and the manner in which each is employed. Both problems are addressed by postulating constraints that are likely to limit future amphibious assaults. These assume continuing military readiness and evolutionary changes to force structures and amphibious tactics.

The constraints can be viewed in terms of four distinct time periods that differ in the nature of the amphibious resources likely to be available:

Period I	1971-1980
Period II	1980-1985
Period III	1985-1995
Period IV	1995 +

Availability and composition of four major resources, landing craft, ships, helicopters, and Marine forces are summarized in Table 1 for each of the above four time periods. Each period differs from the preceding period by introduction of a new resource that can influence the conduct of amphibious operations. The time periods reflect early introduction of new resources based on decisions made now to develop the resources and on normal development cycles.

Each succeeding period provides greater latitude for accommodation to developmental decisions made today. Thus, if the decision were made today to maximize helicopter lift capability and all of the Navy's shipbuilding energies were directed toward designing and building ships that can accommodate helicopters but not landing craft, some residual portion of present landing-craft carrying capability would remain through Period III. Furthermore, there would undoubtedly be instances when amphibious assault performance would be enhanced by augmenting helicopters with landing-craft lift. Conversely, if the decision were made to maximize landing craft capability, some helicopter capability would remain through Period III. Although it is unlikely that the Navy and Marine Corps will abandon the concept of vertical envelopment, a decision to change the lift capability toward more reliance on landing craft and use of helicopters in other roles would also take some time to implement.

Marine force organization limits the choice of delivery techniques. The available helicopter types are not capable of lifting some of the heavy vehicles of a midrange Marine force. Today, these heavy vehicles can be carried ashore in landing craft and landing ships. An embarkation

Table 1

MAJOR AMPHIBIOUS ASSAULT COMPONENTS, 1971-2000

Time Period	Landing Craft	Amphibious Ships	Helicopters	Marine Amphibious Forces
I 1971-1980	Present craft augmented by advanced craft	Present ships including LHA and LST 1179 class	Present helicopters augmented with some heavy-lift helicopters (HLH)	Mid range forces: MAF, MAB, MAU
II 1980-1985	Advanced craft will be available	No change from I	Additional HLH	Same as I, plus helicopter transportable forces
III 1985-1995	No change from II	LHA augmented with some 80-knot ships	New helicopters possible	No change from II
IV 1995 +	?	?	?	?

scheme allocating all of these heavy vehicles to LSTs is not feasible because, under present LST-employment concepts, the LSTs cannot deliver the necessary vehicles as quickly as they are needed. Some combination of landing craft and LSTs, however, could provide the service needed.

The significance of each of the four time periods, in terms of the numbers and types of landing craft and helicopters that might be used to deliver an amphibious force ashore, is discussed briefly below. The discussion is based on requirements to conduct large-scale amphibious assaults (MAF). Smaller-scale assaults at some level can be conducted now, using either all landing craft or all helicopters. The use of smaller forces is not analyzed directly because the capabilities of smaller forces can be inferred from a large-force analysis, whereas extrapolation of a small-force analysis to cover large-force operations would be less valid.

Period I (1971 to 1980)

In the first period, helicopters and landing craft are lifted to the amphibious objective area in the 20-knot fleet that has been under construction since 1961. This fleet includes two newer ship types, the 1179-class LST and the LHA. The available helicopters include the newer types now in service with the fleet (CH46 and CH53) and limited numbers of a new heavy-lift helicopter (HLH). Landing craft include both present types (LCM-6, LCM-8, LCU 1610, and 1637 classes) and limited numbers of advanced craft which are currently being developed. The characteristics of helicopters and landing craft are given in a later section. The Marine forces are limited to midrange forces that are not completely air liftable.

Period II (1980 to 1985)

In Period II, a fully helicopter-transportable force could be in existence if the necessary planning and implementation steps are taken very soon. However, the amphibious fleet in this time period is constrained by the development cycle for new ship types as well as by political and economic considerations related to the life cycle of ships presently in the fleet or under construction. Specifically, the LHA and LST 1179-class ships will be relatively new and are likely to play important roles in amphibious operations.

The LHA is being built to operate with both landing craft and helicopters with very little interference between the two. Thus, use of both modes or either mode is possible in this time period, and both MAF and HLF assaults can be launched.

Period III (1985 to 1995)

Period III is far enough off that some flexibility is possible in planning for amphibious ships, landing craft, helicopters and Marine forces. However, the flexibility is constrained. Although sufficient time is available for modifications to the present amphibious fleet, completely new ship types cannot be designed and built. The most advanced amphibious fleet likely to be available would combine surface-effect ships with LHA, LPD, LST and other existing types. Only evolutionary advances are postulated for advanced landing craft. A single helicopter, more advanced than the HLH, can be available in this period. Beach delivery by ship is a possibility. Marine forces can embody entirely new operational concepts.

Period IV (1995 +)

In Period IV there is almost complete freedom to structure advances in amphibious ships, helicopters and landing craft, subject only to technological constraints. The uncertainties about potential resources obscure attempts to compare different delivery techniques.

Period Selected for Study

This study focuses on Period II and analyzes amphibious assaults by both an HLF and a midrange MAF launched from ships available in that time period and delivered ashore by the helicopters and landing craft expected to be available at that time. Heavy-lift helicopters are expected to be available in sufficient numbers to provide whatever support is desired; however, no new helicopters are postulated. Two development sequences have been tested for landing craft. The first is based on the availability of a full set of advanced landing craft--sufficient to support amphibious assaults based on either force with the desired mix of craft. The second sequence presumes the AALC program is terminated at the end of the development phase, and only conventional craft are available to support amphibious assaults.

Use of Prior Work

The analysis has drawn heavily on the results of past work on the Systems Analysis of Advanced Landing Craft. The earlier work provides both background and a strong analytical starting point. The principal conclusions that have been drawn to date are summarized in Appendix A. The conclusions of greatest significance to the present work are:

- Landing craft performance is extremely sensitive to fleet standoff distance, sea state, and attrition, but is relatively insensitive to small variations in the composition of the Marine force.

- Advanced amphibious landing craft are more cost-effective in delivering men and materiel to assault beaches than conventional landing craft even at a standoff distance of 5 nautical miles. At 25 nautical miles offshore, advanced landing craft are 2.5 to 4 times more cost-effective than conventional landing craft.

- Sending ACVs inland to deliver their cargo, rather than discharging it near the beach, decreases landing craft effectiveness. However, in a particular tactical situation, inland delivery may be critical to the success of an amphibious operation.

- The selection of the most cost-effective set of advanced landing craft is still open. Therefore, several different combinations have been selected from among the craft that are still under consideration in the AALC program.

Basis for Comparisons

Landing craft and helicopter performance is compared in terms of overall amphibious assault performance as measured by SRI's GAMUT model. Given an amphibious fleet, initial shiploads of cargo, the numbers and types of landing craft, helicopters and landing ships, and other environmental factors, the GAMUT model simulates a complete amphibious assault including assault waves, initial drops, serialized unloading and general unloading.* The model selects appropriate loads for landing craft and helicopters and accounts for all of the operational activities associated with movement ashore (loading, maneuvering, wave formation, travel to the objective area, surf crossing, etc.). It also accounts for attrition due to enemy action, mechanical failures and personnel error.

The amphibious assaults are conducted in three parts. First, the scheduled waves are delivered ashore to conform to a precise time schedule. Assault serials are then landed in a prescribed order (which may be modified to conform to a developing tactical situation) and finally, during the general unloading phase, logistic-support cargo and vehicles are delivered ashore in convenient loads and in any sequence.†

Landing craft and helicopter performance is derived from the overall assault performance in terms of selected measures of effectiveness discussed later in this chapter. Because of the complex interactions among landing craft and helicopters, the measures of effectiveness reflect the performance of the entire mix of craft and helicopters selected to support the assault. Conclusions should not be drawn about the performance of an individual delivery vehicle, and care should be exercised in drawing conclusions about classes or types of delivery vehicles.

Amphibious Assault Environments

Two different assault environments have been examined:

- Amphibious assault by a full-scale midrange MAF‡
- Amphibious assault by a Helicopter Liftable Force (HLF).

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* See Appendix D. The GAMUT model is also briefly described in Steinman et al., "Comparisons of Preliminary Designs of Advanced Landing Craft," NWRC/LSR RM 56, Stanford Research Institute, Menlo Park, California, 1970. A forthcoming report will provide a more detailed description.

† Means and Vaughn, op. cit., gives a detailed description of this process.

‡ See Jones, P. S., J. I. Steinman, and A. A. Lynch, Jr., "Analysis of Present Craft in Future Environments," Stanford Research Institute, Menlo Park, California, and Naval Weapons Laboratory, Dahlgren, Va., February 1969.

In the MAF case, a total of 61 ships were used to lift 30,000 troops, and 50,000 tons of equipment and supplies. In the HLF case, 19 to 21 ships were used in varying mixes to lift 13,300 troops and about 18,000 tons of equipment and supplies. The HLF is organized along the lines of a division, but with less strength and lighter equipment, all of which can be delivered by helicopter. This hypothetical smaller force was synthesized at SRI for use in this comparison. It has not been reviewed or approved by the Marine Corps. The force was designed to make available for analytic use a large, helicopter-liftable force. Availability of this force permits the comparison of landing craft and helicopters in the performance of identical missions. SRI prepared this force since no organized, helicopter-liftable force of this size is known to have been prepared under official Marine Corps sponsorship. Both forces are described in Appendix B.

Emphasis is placed on activities during the assault phases of amphibious operations because that is the period in which high-performance delivery vehicles have the greatest impact on mission success or failure. However, some attention is given to general unloading operations, for completeness and to verify the noncriticality of this phase to the analysis.

A nominal standoff distance of 25 nautical miles was used in all investigations. This distance reflects the over-the-horizon goal sought by many amphibious-assault planners and provides adequate sea room for fleet dispersal.

In assaults with the full MAF, LVTs were delivered to the beach by landing craft if suitable craft were available. In most cases, the craft type selected for this task was the air-cushion vehicle landing craft in the JEFF B* configuration (C150). When only slow conventional craft were available, LVTs were launched under way by LSDs that had closed within 3 to 5 nautical miles of the assault beach in accord with current practice. This practice exposes ships to advanced shore-based weapons that will be available in Period II. However, the slow water speeds of LVTs and their heavy weight preclude other delivery means from a fleet standoff of 25 nautical miles. All planing-hull craft loads were delivered to the beach; ACV loads were offloaded from craft just behind the beach, and helicopter loads were delivered to a point 25 nautical miles inland from the beach. A variety of craft mixes was chosen to allow the examination of some

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* Selection of the JEFF B craft over the JEFF A craft does not imply any preference for the B version. The selection was arbitrary.

particular craft characteristics and various combinations of craft types. In each case, craft types were selected first, then the numbers of each craft type were selected to suit the particular requirements. For example, when LVTs were to be delivered by landing craft, the numbers of delivering craft were selected to have adequate (or near adequate) capacity for carrying the LVTs of the force. For each combination of craft, the maximum number that could be carried by the ships of the fleet was selected. Similarly, helicopters were selected first to fit the requirements for vertical lift and second to exhaust the helicopter-carrying capability of the ships of the fleet.*

In each case, the simulated assault time starts when the first wave of delivery vehicles leaves the amphibious ships.† The scheduled waves are delivered as prescribed in the landing plan. Serialized unloading follows immediately after the last scheduled wave. General unloading is allowed to start when 250,000 square feet of vehicles have been offloaded from ships other than LSTs. The GAMUT model monitors offloading and starts general unloading internally.

In the investigations with the HLF, the basic purpose was to allow the helicopters and the landing craft to perform the same mission. This was accomplished by eliminating heavy vehicles, including LVTs, and by limiting helicopter inland penetration. Therefore, all loads were delivered to an area just behind the assault beach.‡

Landing-craft characteristics used in the investigations were based on data available to SRI through March 1971. It should be noted that contracts to design, build, test and evaluate two versions of the JEFF landing craft were let in early 1971.

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* In this research no provision was made for Harrier or other tactical aircraft aboard the amphibious ships.

† Zero simulation time is equal to H-transit time. This convention was adopted to assure that the comparisons reflect the speed with which the initial waves can be carried to the objective areas.

‡ The employment of air-cushion landing craft for cargo deliveries inland is governed by the nature of the terrain. The influence of inland delivery distance on assault performance is discussed in Steinman, J. I., et al., "Comparisons of Preliminary Designs of Advanced Landing Craft," NWRC/LSR-RM 56, Stanford Research Institute, Menlo Park, California, December 1970.

Throughout the analysis, the research team adopted the viewpoint of helicopter proponents. This was done because equally reliable data were not available for both helicopters and landing craft on levels of employment, priority assignments, attrition and other determinants of delivery performance. To avoid charges of bias by association with landing-craft development, an effort was made to provide optimistic conditions for helicopter operations. Wherever there was a range of parameters, such as speed or capacity, the most favorable part of the range was used. Attrition rates for helicopters were assigned at a low level.* No interference from noncargo helicopters was postulated either at the ships or at the landing areas. No helicopters were withdrawn from the landing operations to take part in operations ashore or elsewhere contrary to current operating practice. The intent of these procedures was to provide a level of helicopter operations that was near the upper limit of helicopter delivery capability that is in accord with expected improvements in helicopter capabilities.

Characteristics of Delivery Vehicles

The principal characteristics of the seven landing craft types and the three helicopter types used in the analysis are listed in Table 2.

Measures of Effectiveness

The measures of effectiveness adopted for this study follow the general lines of those used in previous analyses,† but important changes have been made in order to facilitate the comparison of landing craft and helicopters. Primary reliance is placed on two measures:

- Force-time effectiveness
- Total tons delivered (incuding personnel).

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* Attrition experience for helicopters that is applicable to the environment associated with a large-scale amphibious assault was not available. Therefore, attrition factors were assumed for helicopters and were set lower than those used for landing craft (see Grant, A. R., "Vulnerability of Landing Craft," NWRC/LSR RM52, Stanford Research Institute, Menlo Park, California, 1969).

† Jones, P. S., et al., op. cit.

Table 2

CHARACTERISTICS OF DELIVERY VEHICLES

	Cargo Area (sq ft)	Payload Weight (lbs)	Nominal Speed (knots)
LCM-6	412	68,000	8
LCM-8	660	120,000	10
LCU	1,785	375,000	10
P30	451	30,000	35
C30	445	30,000	50
P125	782	125,000	35
C150 (JEFF B)	1,716	150,000	50
CH46	130	4,900	130
CH53	170	8,600	150
HLH*	350†	26,200	90

Note: Some of the craft characteristics have changed since this analysis was completed.

* The heavy-lift helicopter used in this analysis resembles the Sikorsky S-64 in its principal characteristics.

† In attachable pod, normally used with external loads.

Secondary use is made of:

- The point in time that marks the start of general unloading
- The time at which 250,000 square feet of vehicles were delivered ashore
- Delivery rates by type of delivery vehicle
- Delivery vehicle productivity.

Each of these measures is discussed briefly below.

Force-Time Effectiveness (FTE)

This measure has been modified from previous work.* As used in the past, this measure is proportional to the square feet of vehicles delivered to the shore by a specified time, multiplied by the length of time each vehicle has been ashore. Thus, each vehicle of the force makes a contribution to force-time effectiveness that depends on its size in square feet and the time it reached the shore. The rationale for this measure is that the strength, mobility, and firepower of the landed force is roughly proportional to the square feet of vehicles available, and that early deliveries are more valuable than later ones.

While appropriate for comparison among craft types, use of FTE without change would have greatly penalized helicopters relative to landing craft since helicopters operations are concentrated on the highly important early delivery of personnel. A new version of force-time effectiveness was developed that reflects the contribution of both vehicles and personnel. Militarily, vehicle deliveries (equipment, weapons, firepower, and mobility) are no more or less valuable than the personnel deliveries. Neither is fully useful without the other. An effectiveness measure that is proportional to vehicle deliveries and also proportional to personnel deliveries seemed appropriate. The measure adopted is proportional to the product of the two.

Personnel are incorporated into force-time effectiveness by multiplying the number of personnel delivered by the square feet of vehicles delivered then dividing by a suitable constant to make the result arithmetically manageable. The result is then weighted by the length of time

* Jones, P. S., et al., op cit.

since each was delivered to the beach and the values are accumulated as before. The new FTE measure is somewhat more sensitive than the former measure because the two components reinforce each other, as they do in the real world, rather than being considered in isolation from each other.

The initial assault waves have a very large effect on FTE ratings because they arrive early and in larger groups than subsequent deliveries. This effect is particularly noticeable with the LVTs and helicopters. LVTs arrive in the first hour of the assault carrying about 5,000 troops and 80,000 square feet of vehicles. Helicopters start their deliveries within the first half-hour, and deliver 5,000 troops and 50-75 light vehicles within the first hour.

There are theoretical and practical justifications for the new FTE procedure and in addition the results are intuitively acceptable. The Lanchester Equations,* used frequently for force comparisons, show that a unit's effectiveness vis-à-vis an opposing force is directly proportional to both its strength and its firepower. Its firepower is a measure of its ability to cause casualties, while its strength is a measure of its ability to absorb casualties. Against a given opponent, a unit's effectiveness is then clearly proportional to both, or to their product.

The principal shortcoming of the new FTE measure is that the FTE rating is no longer linear. Thus, the overall FTE rating of a fleet of landing craft, helicopters and landing ships is greater than the sum of the FTE ratings of the landing craft, helicopter, and LST components that make it up. This is realistic. The procedure says, in effect, that the effectiveness of a force consisting of two regiments is more than twice the effectiveness of a force of one regiment.

Care must be taken in making comparisons with force-time effectiveness, to ensure that the measures are actually comparable. When comparing the overall effectiveness of one amphibious simulation with another, the overall force-time effectiveness ratings should be used. When comparing landing craft with helicopters, the force-time effectiveness based on total craft deliveries should be used, rather than the total of the separate force-time effectiveness ratings of individual landing-craft types. As statistics for all helicopter types are lumped together in the model, this problem does not exist for helicopters.

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* Morse and Kimball, Methods of Operations Research, John Wiley and Sons, Inc., New York, 1951.

A simplified mathematical development of force-time effectiveness is given in Appendix C.

Total Tons Delivered

This measure sums the tons of cargo (including personnel) delivered by each type of delivery vehicle. Personnel are counted at 240 lbs per man. It is useful as a measure of delivery capability and provides a comparison of the Marine cargo delivered by the different helicopters and landing craft up to a selected time after the start of the assault.

The Time at Which 250,000 Square Feet of Vehicles Were Delivered*

This measure reflects the cumulative performance of the mix of delivery vehicles, and is less heavily influenced than FTE by the initial assault waves. When 250,000 square feet of the vehicles have been landed by landing craft and helicopters, the assault phase of the operation is well under way. However, vehicles continue to arrive for some time. In one run, for example, 250,000 square feet of vehicles had been landed by 6 hours after the start of the operation, but vehicles continued to be brought to shore by craft and helicopters for an additional 10 hours. The 250,000 square feet was chosen more or less arbitrarily to represent a point late in the delivery curve when delivery operations are still in full swing.

For runs with the smaller Helicopter-Liftable Force, a value of 200,000 square feet of vehicles was used.

Delivery Rates by Type of Delivery Vehicle

In evaluating craft and helicopter performance, it is helpful to examine some aspects of delivery rates:

- Tons per delivery
- Tons per delivery vehicle per hour.

Tons per delivery provides a measure of the loading efficiency realized for a particular type of delivery vehicle.

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* This measure does not include vehicles delivered by landing ships.

Tons per delivery vehicle per hour gives a rough measure of the delivery capability of a single delivery vehicle, if taken during an active period. These factors are influenced by the other delivery vehicles in use. To be meaningful for a particular vehicle type, results for a number of different delivery vehicle mixes need to be explored.

Delivery Vehicle Productivity

Delivery vehicle productivity is a measure of the tons of all cargo delivered in a unit time per 1,000 square feet of all of the delivery vehicles (outside area) of a particular type. It is a measure of delivery vehicle performance relative to the space the vehicles of the type under study occupy in (or on) the ships that carry them to the objective area. This measure is most useful when comparing different types of landing craft or different types of helicopters because it provides some insight into how the limited carrying capacity available in an amphibious fleet might be allocated. It also gives a rough comparison between the potential productivity of well deck and helicopter deck area.*

The Variability of the Measures

For economic reasons, replications of simulation runs were not made during this study and therefore there is no direct measure of the statistical variability of the results. However, replications of previous runs using the same basic model have been made to evaluate the variance. In these runs the probable error due to unpredictable variations was about 1.5 percent for total cargo delivered and force-time effectiveness when considering the mix of delivery vehicles as a whole. The probable error in tons of cargo delivered and force-time effectiveness for individual craft types was 3.5-4.0 percent.

Using the new force-time effectiveness algorithm, the overall probable error should be approximately double that of the old, or about 3 percent. The overall probable error in tons delivered should be 2-3 percent. Both random variations and rounding errors contribute to the observed variance.

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* Well deck area earns a bonus because all craft in well decks are preloaded with cargo while in transit to the objective area. Preloading of helicopters is impractical because initial loads are normally personnel loads.

Effectiveness/Cost Rating

Costs can be combined with any of the measures of effectiveness to reflect the return on the Navy's invested dollars. The costs used are, in all cases, the estimated 10-year life cycle costs. For example, the 10-year cost can be thought of as an investment intended to provide a landing capability measured in tons delivered per hour. Thus, effectiveness cost might be expressed as tons delivered per hour per million dollars of 10-year cost. Another measure is FTE per million dollars. Both are used in the analysis.

Simulation Runs

Eleven different simulation runs were made to test the relative performance of different mixes of helicopters and landing craft. A brief description of each run is given in Table 3 together with its purpose. The MAF runs all used both helicopters and landing craft. Landing craft were always needed to bring heavy vehicles and equipment ashore. The HLF runs included one all-landing-craft run and one all-helicopter run. These runs define the total capability of the two different delivery modes and provide limits for analyses of complementary operation. The findings developed from these simulation runs are presented in Chapters III and IV.

Cost Data

The cost data in Table 4 were developed with SRI's landing craft Cost Model, supplemented by other data sources available at SRI.* The figures given represent unit 10-year costs, including research and development, test and evaluation, initial investment and operating cost over the period. Costs are stated in current dollars. The cost category definitions given in Table 5 apply to landing craft. These same general categories were also used throughout the analysis.

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* D. G. Jorgenson, "Cost Model and Cost Estimate," Stanford Research Institute, Menlo Park, California, March 1969.

"Cost Estimates of Weapons, Ships, Aircraft, Missiles and Task Forces," NAVSO P-1986, Office of Comptroller, Dept. of Navy, FY 1968.

"Navy Program Factors," OPNAV-90P-02, Revised 1 September 1970, Office of Chief of Naval Operations, Dept. of Navy.

Table 3

SUMMARY OF SIMULATION RUNS

Run No.	Force	Landing Craft Mix	Heli-copter Mix	Purpose of Run
30-8	MAF	C30 C150	CH46 CH53 HLH	Compare helicopter performance with that of an all-ACV mix.
30-9	MAF	C30 P125 C150	CH46 CH53 HLH	Compare helicopter performance with that of a diversified craft mix.
30-10	MAF	P30 C150	CH46 CH53 HLH	Determine effects of substituting the P30 for the C30 in the mix.
30-11	MAF	LCM 6 LCM 8 C150	CH46 CH53 HLH	Determine the effects of substituting conventional landing craft for small and medium advanced craft.
30-12	MAF	C30 P125 C150	CH46 CH53 HLH	Same as that of Run 30-9 except that restrictions on helicopter operations were removed.
30-13	MAF	LCM 6 LCM 8 LCU	CH46 CH53 HLH	Determine effects of using only conventional landing craft with helicopters.
31-1	HLF	C30 C150	none	Determine capabilities of a landing craft-only mix with a helicopter-liftable force.
31-3	HLF	none	CH46 CH53 HLH	Determine capabilities of a helicopter-only mix with a helicopter-liftable force.
31-4	HLF	C30 C150	CH46 CH53 HLH	Determine capabilities of a mix of helicopters and landing craft with the helicopter-liftable force. Ship environment favors helicopters.
31-6	HLF	C30 C150	CH46 CH53 HLH	Same as that of Run 31-4, but 6 LKAs substituted for 8 LPHs.
31-8	HLF	C30 C150	CH46 CH53 HLH	Same as that of Run 31-4, but 8 LPDs substituted for 8 LPHs.

Notes: Not all of the above runs will be fully analyzed. The omitted runs were either incomplete or redundant.

Table 4

UNIT COST DATA USED IN
COST-EFFECTIVENESS DETERMINATION

	10-Year Cost ($ millions)
Ships	
LKA	$ 104
LHA	115
LPD	85
LSD	74
LST	67
LPH	151
Landing Craft	
LCM-6	.59
LCM-8	.91
LCU	2.90
P30	3.6
C30	4.5
P125	6.7
C150	11.0
LVTP7	1.8
Helicopters	
CH46	4.1
CH53	5.7
HLH	8.0
Force (Per Man)	
Ground	.0865
Air	.3140
Service	.1110

Table 5

COST CATEGORY DEFINITIONS FOR LANDING CRAFT

Chart of Accounts	Definitions
RDT&E	
1. Engineering & development support	Initial design engineering and support costs
2. Initial tooling and prototype fabrication	Tool design and fabrication, plus complete construction cost of first craft
3. Test and evaluation	Contractor test and evaluation including planning, instruction, operating costs, and data analysis
Initial Investment	
1. Sustaining engineering	Design modifications, systems integration, shop and vendor liaison, and so forth
2. Sustaining tooling	Tool planning, jigs, fixtures, and so forth
3. Fabrication	Complete cost to build total craft required for one MAF; summation of account items 4, 5, and 6 below
4. Hull fabrication	Total procurement cost for hull only (Cost Category 1)
5. Propulsion	Turbines, transmission, shafting, lifting, lift or foils, propellers (Category 2)
6. Other construction	Electric plan, communications and control, auxiliary systems, outfit and furnishings (Categories 3-6)
7. Initial spares	Pipeline and depot spares to complement initial craft procurement
8. Support equipment and modification	Support requirements and modifications to fleet caused by new craft
9. Initial training	Training to obtain proficiency in new specialties required by introduction of a new craft
10. Program management	Operations, liaisons, offices, documentation, and the like
Annual Operations	
1. POL	Consumption of petroleum, oil, and lubricants
2. Support costs	Engineering changes and improvements
3. Peacetime attrition	Operational losses
4. Operating personnel	Military pay and allowances and support cost of craft operators
5. Annual Training	Annual, transitional, and replacement training; schools, and instructor pay
6. Shipboard maintenance: labor	Field level corrective, preventive, and servicing maintenance
7. Shipboard maintenance: material	Field level replacement spares
8. Overhaul maintenance	Depot overhaul of structure, engines and all other systems
9. Support equipment	Maintenance of equipment that was installed on ships to handle the advanced craft
10. Depreciation	Wearing out of conventional craft

II CONCLUSIONS

The relative effectiveness and cost of several mixes of landing craft and helicopters have been compared for both MAF and HLF assaults in time Period II. In all cases, the amphibious fleet launches the assaults from 25 nautical miles offshore and the assault objectives lie no more than 25 nautical miles inland from the coast. The helicopter mixes are optimized for the force, subject to the constraints imposed by the helicopter carrying capacity of the different amphibious ships in the assault force, and considering helicopter unit integrity. Several landing craft mixes have been tested. Some include two or three types of advanced landing craft. In one run only conventional craft are used.

The principal conclusions are set forth below for each of the two different forces studied.

Full Marine Amphibious Force

Initial lifts and loads were specified to meet assault objectives. Some landing craft were always needed to transport the 250 vehicles in the force that are too heavy to be lifted by helicopter. Helicopters and landing craft were allowed to compete for the balance of the personnel, vehicles and cargo.

- Landing craft are more productive and more cost effective than helicopters in delivering this force ashore.

- In ten hours of operation, several of the mixes of advanced landing craft deliver twice the tonnage delivered by helicopters.

- The most attractive advanced landing craft mix provides about four times the FTE of the helicopters.

- The JEFF configuration (C150) is the most cost effective of the advanced landing craft. This craft is four times as productive as the average helicopter and is 75-85 percent more cost effective.

- The superiority of landing craft over helicopters depends on the development of advanced landing craft.

- When only conventional landing craft are available, landing craft are less productive than helicopters.

- Helicopter capabilities were fully exploited during these runs.

Helicopter-Liftable Force

Initial lifts and loads were specified to meet assault objectives. Because both helicopters and landing craft delivered to the same objectives ashore, initial loads could be carried by either delivery vehicle type or by combinations of the two. When both delivery vehicle types are available, they compete for all loads.

- Under conditions highly favorable to helicopter operations (shorter distance, lighter loads and fewer craft) combined mixes of helicopters and landing craft were still substantially more effective and more cost effective than either helicopters alone or landing craft alone.

- Comparison of helicopter mixes and landing craft mixes gave mixed results in almost all categories. Usually, helicopter mixes were superior, although not consistently. On balance, the edge should be given to helicopter mixes.

- JEFF type craft are highly desirable to support HLF operations. Even though, on a tons-per-unit-cost basis, helicopter mixes were about equal to the advanced landing craft mixes, the C150 performance was 20-50 percent higher than the helicopter performance.

III RESULTS OBTAINED WITH MARINE AMPHIBIOUS FORCE

Six different amphibious assaults were simulated for the full MAF. These simulation runs were based on the same amphibious fleet and used the same mix of cargo-carrying helicopters. They differed in the types of landing craft carried and in the fraction of the force that was available for movement ashore by helicopter.

Table 6 summarizes the ships, landing craft and helicopters used in four of the six simulated assaults and gives the estimated 10-year life cycle costs for the different components of the assault force. The ship types selected for the amphibious fleet are those types expected to be available in Period II (1980 to 1985). The numbers of each type are selected by analysis with SRI's EMBARK* model which loads the MAF onto the selected ship types. EMBARK recognizes wave and serial integrity requirements; it accounts for cargo preloaded in landing craft; it accommodates the need to serially offload the assault-phase cargo; it reflects the carrying characteristics of each ship type; and it spreads cargo assignments so as to expose the maximum number of landing craft and helicopter loading positions at all times. Landing craft and helicopters are selected for efficiency in carrying scheduled waves and assault serials and for full occupancy of the available landing-craft and helicopter carrying spaces.

Summary Results

Table 7 lists selected summary results for the four MAF simulation runs 10 hours after the start of the assault. Results for the advanced landing-craft runs (30-8, 30-9, 30-10) are quite similar and are substantially better than the result for conventional landing craft (15 percent better in tons delivered, 28 percent better in FTE, and 75 percent better in time to deliver 250,000 square feet of vehicles). When advanced craft are used, the landing-craft mix as a whole delivered about twice as many tons of cargo as the helicopters and produced about four times the force effectiveness. On a percentage basis, helicopters delivered 27-30 percent of the total force tonnage, while landing craft delivered 48-51 percent

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* EMBARK is described in Jones, et al., op. cit.

Table 6

COMPONENTS OF SIMULATED MAF ASSAULTS

	Run 30-8	Run 30-9	Run 30-10	Run 30-13
Ship types				
LHA	6	6	6	6
LPH	8	8	8	8
LPD	7	7	7	7
LSD	12	12	12	12
LKA	6	6	6	6
LST	22	22	22	22
Landing craft				
LCM-6	--	--	--	147
LCM-8	--	--	--	56
LCU	--	--	--	41
P30	--	--	186	--
C30	108	54	--	--
P125	--	74	--	--
C150	68	52	68	--
Helicopters				
CH46	120	120	120	120
CH53	60	60	60	60
HLH	6	6	6	6
LVTP-7	228	228	228	228
10-year costs (millions of dollars)				
Ships	$ 5,479	$ 5,479	$ 5,479	$ 5,479
Landing craft	1,234	1,311	1,418	256
Helicopters	882	882	882	882
LVTs	410	410	410	410
Force	5,175	5,175	5,175	5,175
	$13,180	$13,257	$13,364	$12,202

Table 7

SUMMARY RESULTS FOR SELECTED MAF SIMULATIONS

	Run 30-8 (Craft C30, C150)*	Run 30-9 (Craft C30, P125, C150)*	Run 30-10 (Craft P30, C150)*	Run 30-13 (Craft LCM-6, LCM-8, LCU)*
Measures of effectiveness				
Tons delivered:				
By landing craft	17,222†	17,555†	17,617†	7,046
By helicopters	9,449	9,268	9,474	9,154
By landing ships	8,418	8,150	8,150	14,070†
Total	35,090	34,974	35,245	30,264
Force-time effectiveness:				
By landing craft	2,864	2,928	3,041	464
By helicopters	765	768	721	926
Overall	7,865	7,922	7,980	6,163
Time general unloading starts (minutes)	266	262	290	442
Time 250,000 square feet of vehicles delivered	335	336	329	597

* Plus helicopters.

† Includes LVTs (5,130 tons).

and landing ships about 23 percent. When conventional craft were used, landing craft delivered only 23 percent of the total force tonnage, helicopters delivered 30 percent, and landing ships delivered 47 percent. The FTE attributable to conventional craft is also low--less than one-sixth the FTE of the advanced landing craft and only one half of the helicopter FTE. When advanced craft are used, general unloading starts between 4 and 5 hours after the start of the assault; however, with conventional craft it is delayed until more than 7 hours after the start. In a similar fashion, delivery of 250,000 square feet of vehicles occurs about 5.5 hours after the start of the assault when advanced craft are used and requires almost double that time when conventional craft are used.

The summary results suggest that the helicopter mix is very attractive when compared with conventional landing craft, but advanced landing craft are more productive than helicopters when delivering an MAF ashore.

Delivery Characteristics

Important insights into the relative productivity of helicopters and landing craft can be obtained by a detailed examination of the simulation run results. Figure 1 shows the cumulative tons of cargo delivered plotted against elapsed time for Run 30-9 in which the MAF is delivered ashore by a mix of helicopters and advanced craft (C30, P125, C150). The other runs with advanced craft yield very similar results. Run 30-13 using helicopters and conventional craft produced a curve roughly parallel to the curve of Figure 1, but 20 percent to 60 percent lower. In Figure 1, the number of tons delivered rises sharply for the first hour, reflecting the impact of the scheduled waves. The slope remains relatively constant at a lesser value from Time: 1 hour to Time: 13 hours. This slope represents the sustained delivery capability of the combined mix of helicopters, landing craft and landing ships. After 13 hours, some of the ships (including the LSTs) are emptied. As a result, fewer loading positions are available and the helicopters and landing craft are not fully used.

Figure 2 gives further insights by showing the total tons delivered by all delivery vehicles during each hour for the same run (Run 30-9). The principal characteristics of this curve are typical of other runs with advanced craft. The initial surge reflects the delivery of vehicles by preloaded craft (mostly LVTs). Thereafter, the delivery rate falls off sharply until the craft return with their second loads. The sawtooth results from the wave effect in craft operation. Preloaded craft are

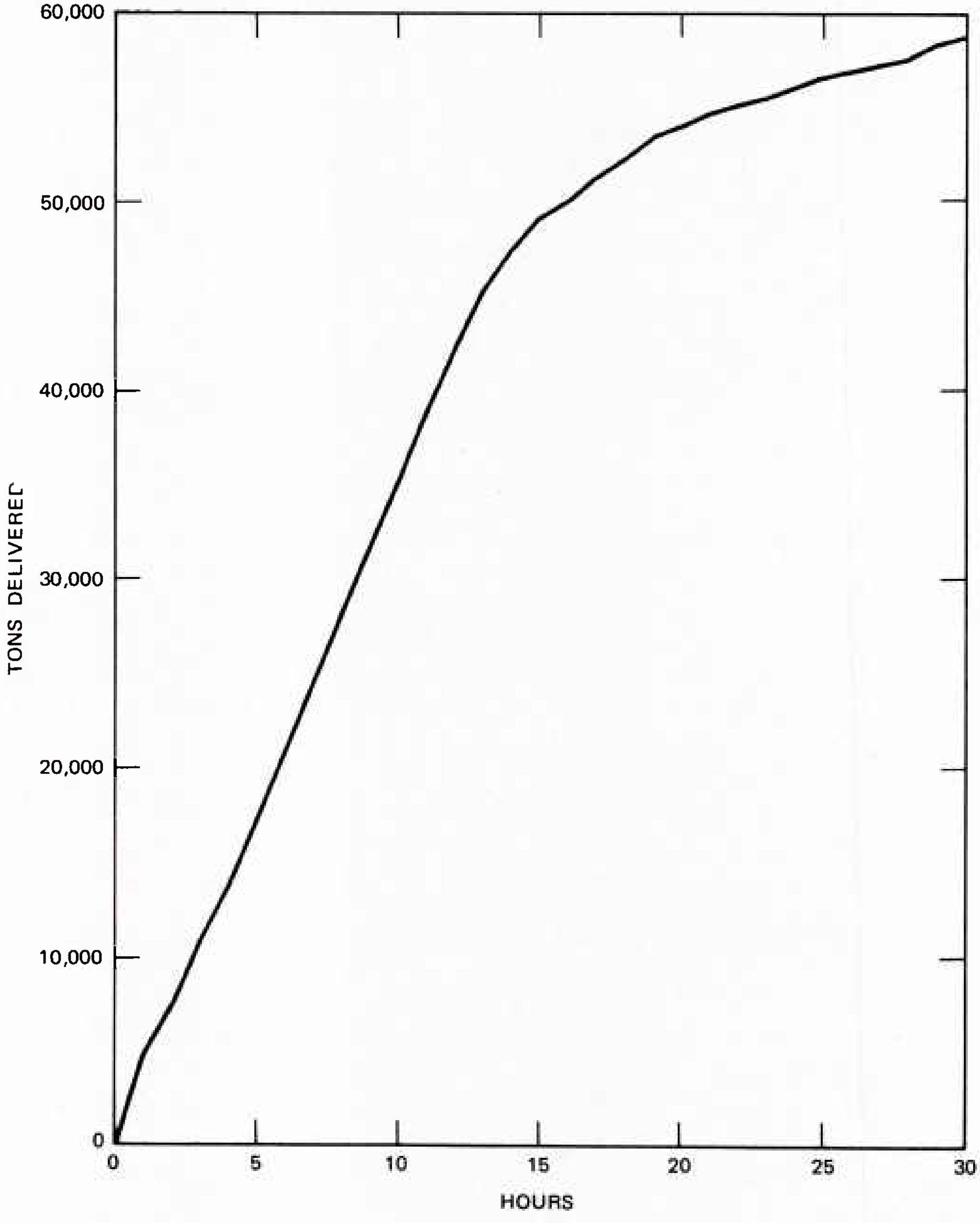

FIGURE 1 CUMULATIVE DELIVERY OF TONS OF CARGO, RUN 30-9—FULL MAF

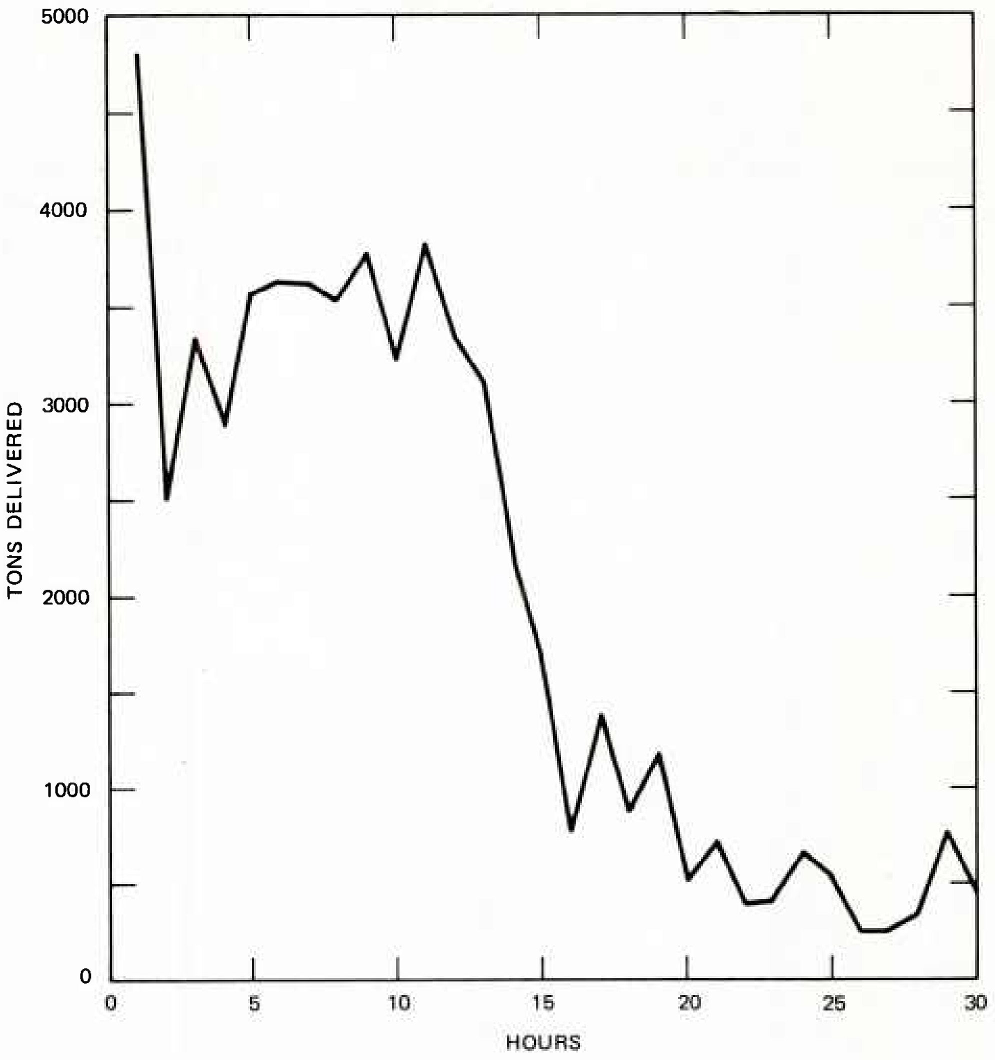

FIGURE 2 TOTAL TONS DELIVERED EACH HOUR, RUN 30-9—FULL MAF

unloaded at the beach in closely spaced waves as rapidly as unloading positions can be made available. As the assault progresses, queuing delays at the beach and at the ships tend to spread the craft out so that the wave effect becomes less apparent. Nonetheless, it persists in some degree throughout the assault. Helicopters appear less subject to the wave effect, primarily because their cycle time is about the same length as the reporting period, but also because they are not preloaded; loading and unloading times are short; and they tend to be more uniformly spaced at the beginning of the assault. Helicopters are scheduled into a small number of operating spaces over a period of time.

Perhaps the most distinctive feature of Figure 2 is the sharp drop-off after about 12 hours, which corresponds to the shoulder in Figure 1. After

12 hours, the principal ships remaining to be unloaded are LKAs and LPDs that still contain considerable cargo but have relatively few loading spots to receive helicopters and landing craft. The last ships to be unloaded are the LKAs, which exhibit long craft loading times and also operate very slowly with helicopters because of the single helicopter platform. After about 15 hours, the operation is essentially reduced to the offloading of pallets from LKAs by craft, a relatively slow operation that drags on for another day or so.

Figure 3 shows the tons delivered each hour by delivery vehicle type for Run 30-9. It is evident from these curves that the initial surge is entirely due to landing craft. Thereafter landing craft deliveries per hour fall off rapidly. The first drop can be attributed

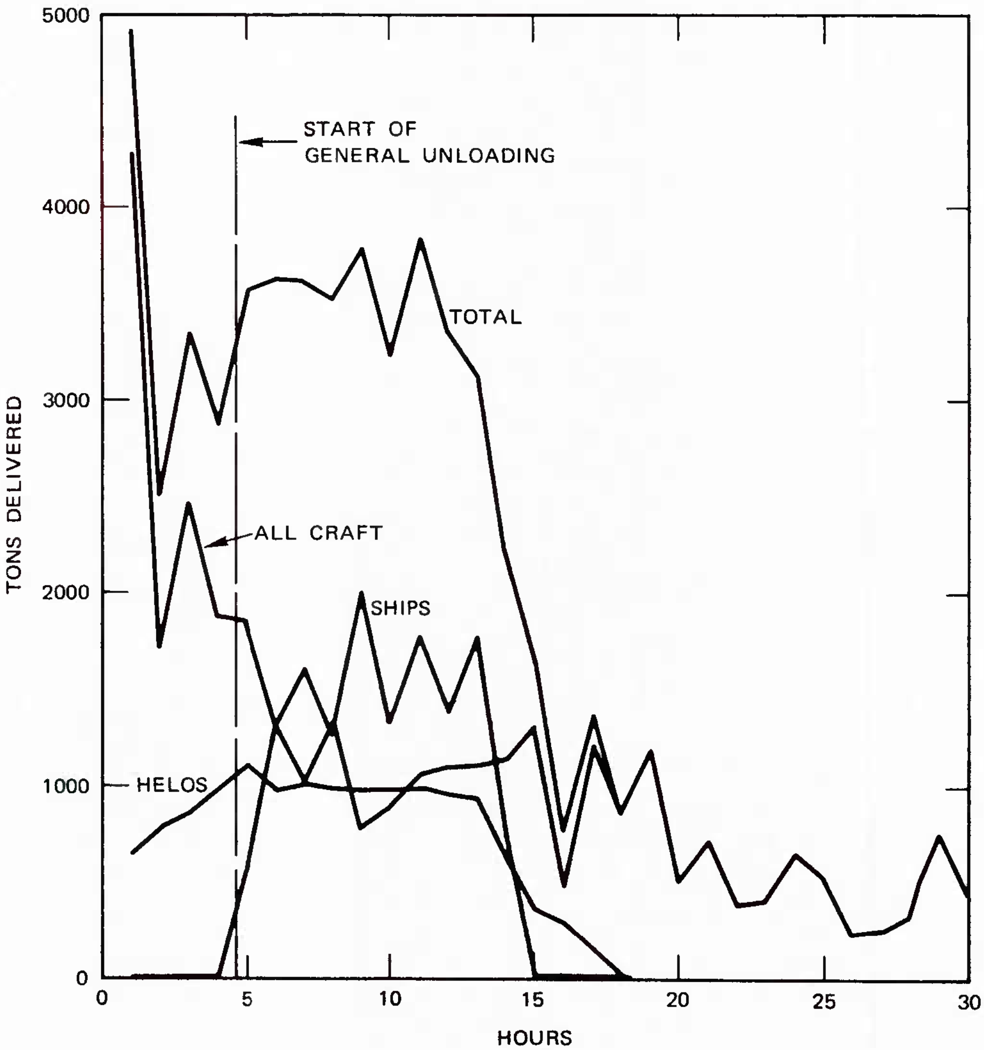

FIGURE 3 TONS DELIVERED EACH HOUR BY TYPE OF DELIVERY VEHICLE, RUN 30-9

to rounding out the craft delivery cycle by adding return transit and loading time as craft return to the amphibious ships for their second and subsequent loads. The influence of queuing delays at the beach and at the ships is also a factor. The delivery rate between Time: 2 hours and Time: 5 hours reflects landing craft capability to offload vehicles from amphibious ships. After 5 hours, two factors contribute to the further decline of the craft delivery rate: (1) general unloading has commenced and loading times for palletized cargo are very much longer than vehicle loading times, and (2) by this time eleven ships are completely unloaded, reducing the number of available loading stations.

Helicopter deliveries rise to a maximum rate at Time: 5 hours, stabilize until about Time: 13 hours, and then fall of rapidly. The lack of an early surge for helicopters occurs because in early trips helicopters carry primarily lightweight personnel loads. The fall-off after 13 hours results from a shortage of loads available to helicopters. The wave effect is not evident for helicopters in this run.

Ship deliveries start late because of the time required to install causeways. Deliveries are approximately level, though uneven, until all LSTs are empty at Time: 15 hours.

Helicopter Cargo Restrictions

In the assault simulations, each helicopter type was restricted to carrying only vehicles that fall within its weight-carrying capacity. The large number of heavy vehicles and equipment was carried ashore by landing craft and landing ships. As a result only about 50 percent of the vehicles in the MAF were available for helicopter delivery.

One might then ask to what extent helicopter performance was limited by the cargo that was available to them. This question was answered by simulating an assault in which all cargo was available to helicopters (Run 30-12). When the results of this run were compared with a run that is identical except for helicopter cargo restrictions, little difference was observed in overall performance, or in helicopter performance. In the unrestricted run helicopters were only slightly more effective than in the restricted run (see Table 8). This suggests that the helicopters were already being fully exploited during the assault phase. This conclusion is reinforced by the observation that helicopters did not spend very much time waiting to load in any of the simulation runs until late in the problem (usually about Time: 12 hours).

Table 8

SUMMARY DATA FOR RESTRICTED AND UNRESTRICTED HELICOPTER CARGO--10 HOURS AFTER START OF ASSAULT

	Run 30-9 Restricted	Run 30-12 Unrestricted
Total tons delivered by helicopters	9,268	9,264
Total tons delivered by all means	34,974	34,481
Percent delivered by helicopters	26.5%	26.9%
Force-time effectiveness, helicopters	768	882
Force-time effectiveness, all means	2,275	2,268

To further test helicopter capability, an assault was simulated in which helicopters were allowed to carry 100 percent of the cargo and no landing craft were used. In that case, after Time: 10 hours, the helicopters had delivered 9,323 tons, very slightly more than they delivered in either Run 30-9 or Run 30-12. The helicopter FTE contribution was 1,142 for the all-helicopter assault, higher than the runs reported above. The increase in FTE is accounted for by the delay in introducing palletized cargo, which does not enter into the calculation of FTE. In other runs, helicopters participated in the early start of general unloading and lost the benefit of some vehicle-carrying capability.

It seems clear that during the assault phase of an MAF-sized amphibious operation, there is a very definite upper limit on the helicopter delivery capabilities, and further that advanced landing craft, if available, will perform the bulk of the delivery activities. This is especially true of the 250 vehicles in the MAF that weigh in excess of 35,000 lbs. However, regardless of weight limitations, most of the vehicles, equipment and cargo for an MAF are most effectively delivered by means other than helicopter because of limitations on the number of helicopters that can be used.

Performance of Delivery Vehicle Types

The contribution that individual delivery vehicle types make to the simulated amphibious assaults has been measured up to Time: 10 hours.

At this time all are nearly fully occupied, with some landing craft degradation because of the introduction of palletized cargo. Table 9 lists the average tons per hour per vehicle and average tons per vehicle delivery, for seven different landing craft types and for the 186 helicopters as a group. The C150 performance is outstanding in both categories. It is exceeded only by the LCU in tons per delivery. The C150 is four times as productive as the average helicopter and more than twice as productive as its nearest craft competitor. The C30 is more productive than the LCM-6 and LCM-8 (which have more than twice the payload capacity of the C30) but only 65 percent as productive as the average helicopter. The P125 is more productive than the average helicopter but less than one-third as productive as the C150. The redesigned P125, which has a larger cargo well than the version used here, should increase its productivity by about 50 percent. The average performance of each type of delivery vehicle is illustrated in Figure 4.

Table 9

UNIT DELIVERY-VEHICLE PERFORMANCE

Delivery Vehicle	Run 30-8	Run 30-9	Run 30-10	Run 30-11	Run 30-13
	Average Tons per Delivery Vehicle per Hour				
C30	3.2	3.4	--	--	--
P30	--	--	2.1	--	--
P125	--	6.2	--	--	--
C150	20.2	21.3	20.2	21.4	--
LCM6	--	--	--	1.1	1.3
LCM8	--	--	--	2.8	2.5
LCU	--	--	--	--	9.2
Helicopters (all)	5.1	5.0	5.1	5.1	4.9
	Tons per Delivery				
C30	7.6	7.6	--	--	--
P30	--	--	5.6	--	--
P125	--	17.6	--	--	--
C150	52.2	53.1	53.8	52.5	--
LCM6	--	--	--	5.0	7.2
LCM8	--	--	--	12.8	14.3
LCU	--	--	--	--	57.6
Helicopters (all)	4.8	4.8	4.6	4.7	4.9

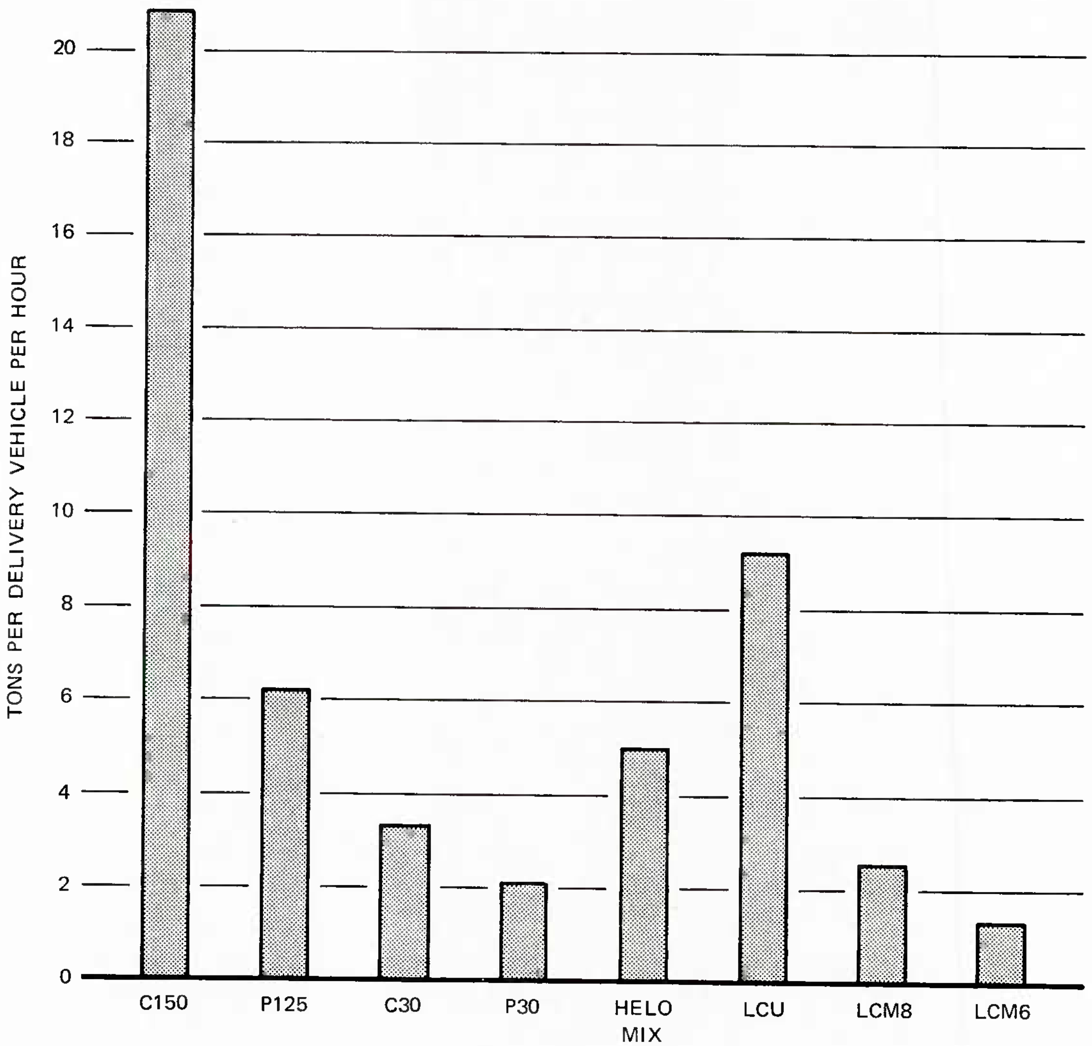

FIGURE 4 AVERAGE TONS PER HOUR DELIVERED AFTER TEN HOURS BY TYPE OF DELIVERY VEHICLE

Delivery Vehicle Productivity

Productivity is essentially a measure of performance per square foot of delivery vehicle, and therefore is a rough indication of the potential value of the carrying space within the ships. Productivity varies with the type of delivery vehicle. The tabulation below summarizes the productivity of the various delivery vehicles used with the MAF, in tons delivered per hour per 1000 square feet of outside delivery vehicle dimensions. In this case, the helicopter and the C150 come out about even, with the other landing craft doing less well. All of the advanced landing craft do at least as well as the best conventional craft (LCU) on this basis.

Delivery Vehicle	Run 30-8	Run 30-9	Run 30-10	Run 30-13
C30	2.6	2.8	--	--
P30	--	--	2.5	--
P125	--	3.7	--	--
C150	5.0	5.3	5.0	--
LCM6	--	--	--	1.7
LCM8	--	--	--	1.7
LCU	--	--	--	2.6
Helicopters (all)	5.4	5.3	5.4	5.2

Comparison of Helicopter Types Using GAMUT-H

The full GAMUT model handles three types of helicopters, and treats each separately; however, it does not provide separate statistics for the different helicopter types. In the program output, all helicopter performance data are lumped together. This procedure is adequate for the comparisons of helicopters and landing craft because the principal comparisons are between total landing-craft performance and total helicopter performance.

However, it is of interest to know how the different types of helicopters compare with each other in their contributions to the assault effectiveness. This information cannot be reconstructed from GAMUT output, but data bearing on the subject have been developed using GAMUT-H, a subset of GAMUT that is restricted to helicopter operations. GAMUT-H handles up to six different types of helicopters and is adaptable for land-to-land operations as well as ship-to-shore.*

GAMUT-H was used to simulate a fully helicopter-liftable force of about 8,000 troops, representing the assault elements of two RLTs. The delivery distance was 50 nautical miles. The results of this simulation shed some light on relative helicopter performance. The data listed in Table 10 show the relative performance of four different helicopter types in a mix very similar to the one used in the full GAMUT runs. Performance is measured up to 3 hours after the start of the assault.

Table 10

RELATIVE PERFORMANCE OF FOUR HELICOPTER TYPES AT TIME: 3 HOURS

	Helicopter Type				
	UH-1N	CH46E	CH53D	HLH	Total
Number	24	120	60	6	216
Speed (knots)	110	130	150	90	--
Capacity (lbs)	2,500	4,900	8,600	26,200	--
Tons delivered	97	690	730	15	1,673
Force-time effectiveness*	--	2,415	2,724	--	16,954
Tons/helicopter/hour	1.3	1.9	4.1	0.8	2.7

* Computed in the same manner as in GAMUT, but cumulated more frequently and at a higher rate. Therefore, not directly comparable to FTE from the GAMUT runs.

* This model was developed for HQ USMC and a program deck has been provided to them. It is described by J. Perrin and A. Grant in "Vertical Lift Helicopter Model (GAMUT-H)," which is Appendix B to "Marine Aviation Resource Model," Stanford Research Institute, Menlo Park, California, March 1971.

The UN-1N performed relatively poorly in this mix because of its low capacity and small numbers. The heavy-lift helicopter also performed poorly but for a different reason. The HLHs were artificially delayed at the start; furthermore, their large capacities could not be efficiently used by the type of loads that were available (mostly troops and small and medium vehicles).

Overall, the mix delivered about 2.7 tons per helicopter per hour, a figure that is compatible with the results obtained with the full GAMUT model (5.0 tons per helicopter per hour). The variation in mean performance is a direct result of differences in vehicle characteristics. The average vehicle weight for the GAMUT runs is about twice that value used for this GAMUT-H run.

It should also be noted that the delivery rate for the CH53 is about twice that of the CH46. The force-time effectiveness of 60 CH53s was higher than the FTE of 120 CH46s.

Cycle Times

Helicopter cycle times are relatively constant because helicopters are given cargo priority at ships and because they have short loading and unloading times. Figure 5 shows the distribution of cycle times for all helicopters in Run 30-9. The distribution is bimodal with the first peak reflecting personnel and vehicle loads for which loading and unloading times are very short. The second peak reflects cargo cycle times where helicopters are delayed by the limited loading positions and by longer loading and unloading times.

In sharp contract to helicopters, landing craft cycle times vary widely, depending heavily on cargo type, especially for ACVs. Craft carrying personnel and vehicle loads normally have short loading and unloading times compared with pallet loads. Therefore we expect shorter cycle times during the assault phase than during general unloading.

Figure 6 shows the frequency of cycle times for C150 craft in Run 30-9. The multi-modal character is very prominent. The first spike, with cycle times as low as 45 minutes, represents landing-craft trips delivering preloaded LVTs for which there is no loading time and very short unloading time. The second spike represents vehicle and personnel delivery. Much further off to the right are two clusters of cycle times, which represent trips for the delivery of pallets, and also include the effects of attrition delays and some queuing at the ships. A similar pattern is noted with the P125 craft (Figure 7) where the early spike

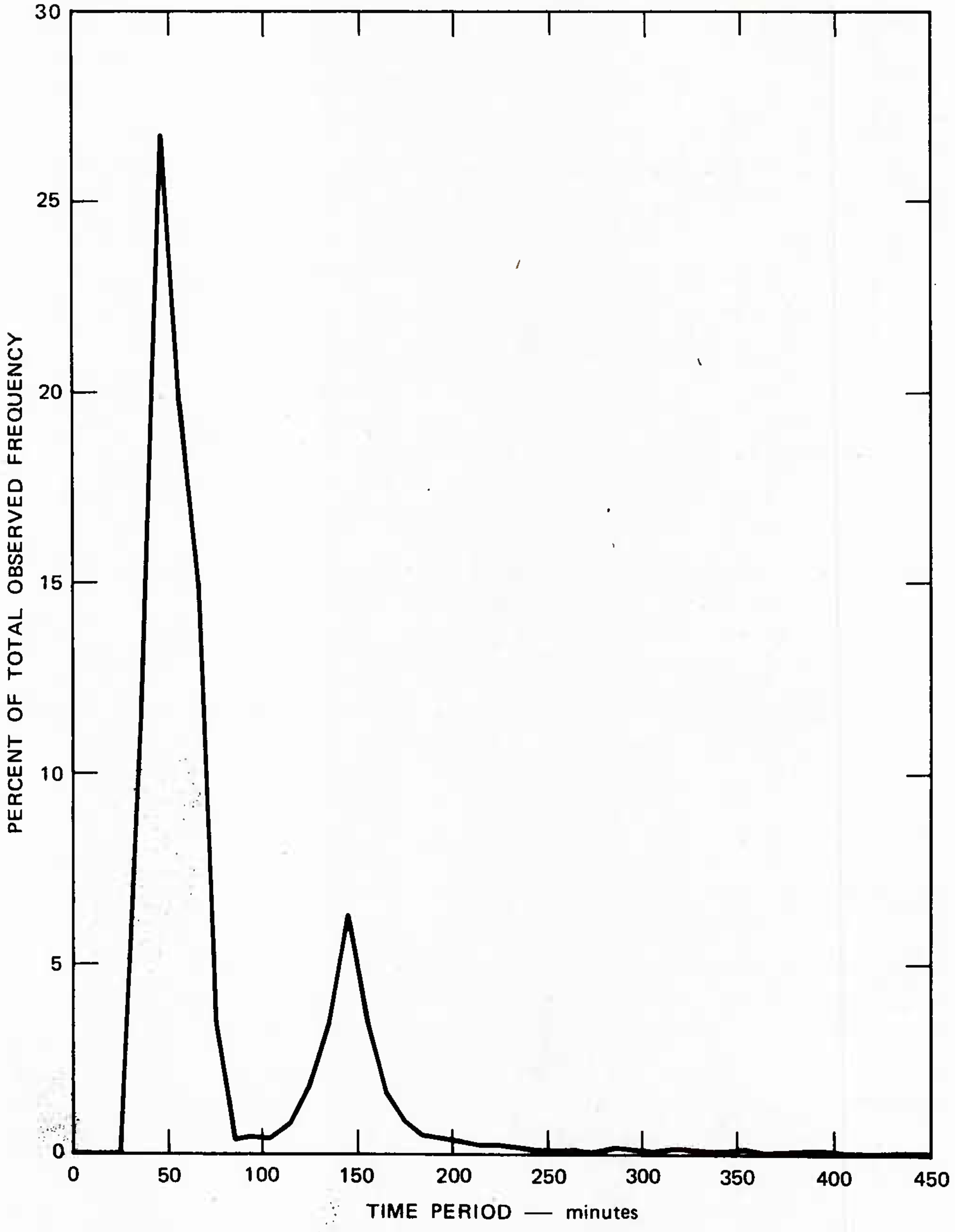

FIGURE 5 DISTRIBUTION OF CYCLE TIMES FOR HELICOPTERS AFTER 50 HOURS, RUN 30-9

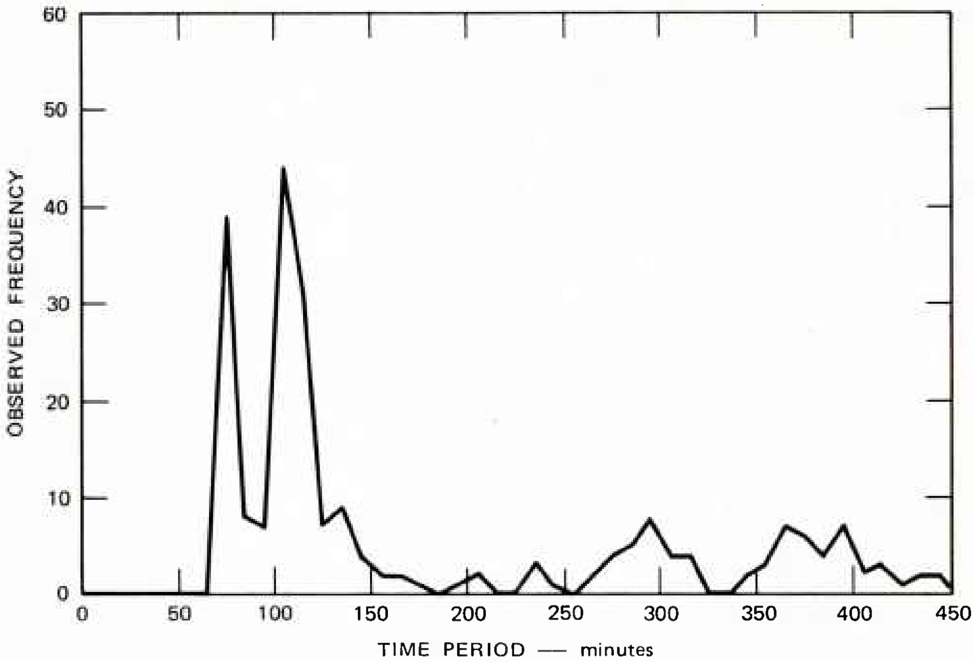

FIGURE 6 DISTRIBUTION OF CYCLE TIMES FOR C150 LANDING CRAFT AFTER 50 HOURS, RUN 30-9

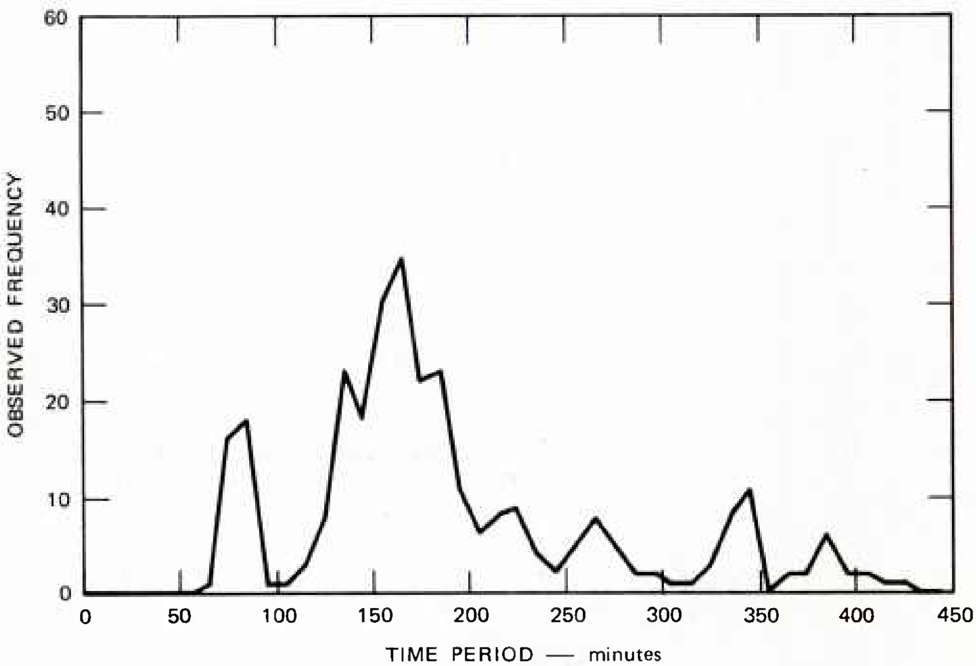

FIGURE 7 DISTRIBUTION OF CYCLE TIMES FOR P125 LANDING CRAFT AFTER 50 HOURS, RUN 30-9

reflects performance with preboated loads (including some LVTs), followed by a large, wider spike reflecting delivery performance for vehicles and personnel. The series of smaller humps reflect pallet delivery performance and the influence of attrition delays.

The C30 (Figure 8) also displays a double spike representing preboated loads (no LVTs) and the later deliveries of vehicles and personnel.

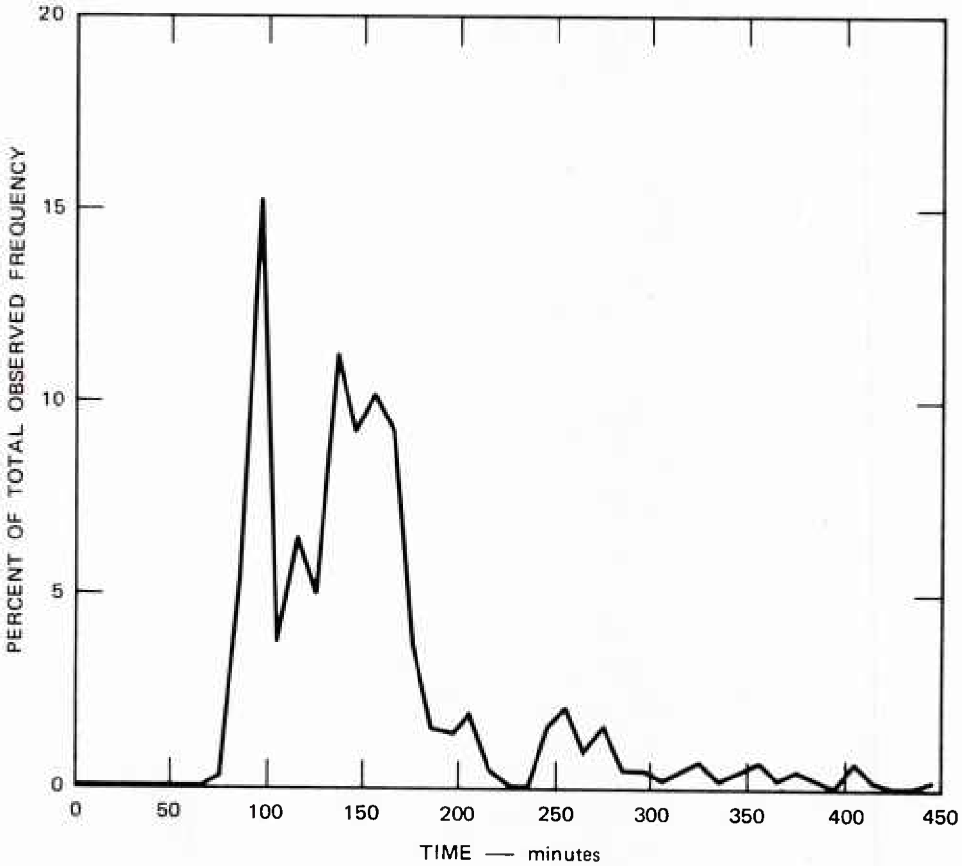

FIGURE 8 DISTRIBUTION OF CYCLE TIMES FOR C30 LANDING CRAFT AFTER 50 HOURS, RUN 30-9

Effectiveness/Cost Ratings

As pointed out in the Introduction, the effectiveness of landing craft and helicopters is derived from the effectiveness of the assault. One measure of helicopter effectiveness (tons delivered per helicopter hour) is sensitive to the cargo carried. The effectiveness of individual vehicles is also influenced by fleet composition, assignment of LVT delivery, fleet standoff distance, and a host of other assault parameters. Some insights into the relative cost effectiveness of the different craft mixes can be obtained by comparing results for the four runs that are identical except for landing craft mix--Runs 30-8, 30-9, and 30-13. These runs are compared below in terms of FTE and tons delivered per hour for the first ten hours.

	Run 30-8 (Craft C30, C150)	Run 30-9 (Craft C30, P125, C150)	Run 30-10 (Craft P30, C150)	Run 30-13 (Craft LCM-6, LCM-8, LCU)
Total assault force cost (millions of dollars)	$13,180	$13,257	$13,364	$12,202
FTE	7,865	7,922	7,980	6,163
FTE/million dollars	0.596	0.597	0.597	0.505
Tons delivered per hour	3,509	3,497	3,525	3,026
Tons/hour/million dollars	0.266	0.264	0.264	0.248

The three runs with advanced craft produced very similar results. All three craft mixes contained about the same number of C150 craft. Therefore, the results above suggest that for these runs, we are unable to differentiate among the relative attractiveness of the C30, P30, and P125 craft. Run 30-13 using present-day landing craft is appreciably less effective (and less cost-effective) than the runs using advanced craft. The advanced craft runs enjoy an advantage of 18 percent in FTE/cost, and 6 percent in tons/hour/dollars of cost.

It is also informative to examine effectiveness/cost ratings based on only those costs associated with helicopters and landing craft, omitting the costs of the ships, the force and other aircraft. This allows a comparison of the marginal effectiveness of helicopters and craft.

	Run 30-8	Run 30-9	Run 30-10	Run 30-13
Helicopters				
10-year life cycle costs (millions of dollars)	$882	$882	$882	$882
FTE	765	768	721	926
FTE/million dollars	.87	.87	.82	1.05
Tons delivered per hour	950	927	947	915
Tons/hour/million dollars	1.08	1.05	1.07	1.04
Landing craft				
10-year life cycle costs (millions of dollars)	$1,234	$1,311	$1,417	$257
FTE	2,864	2,928	3,041	464
FTE/million dollars	2.32	2.23	2.15	1.81
Tons delivered per hour	1,722	1,756	1,762	705
Tons/hour/million dollars	1.40	1.34	1.24	2.75

Discounting Run 30-13 which is unattractive on an overall basis, landing craft are substantially more attractive than helicopters on the basis of both FTE and tons delivered per hour.

Even more cautious observations might be made about the relative performance of individual craft types and helicopters. For this purpose, only one measure of effectiveness has been used: tons per delivery vehicle per hour. The costs used are the costs for the craft or helicopters only and do not reflect the costs of the amphibious ships or the Marine force. The relative effectiveness/cost results 10 hours after the beginning of the assaults are:

Delivery Vehicle	Tons/Hour/Million Dollars Run 30-8	Run 30-9	Run 30-10	Run 30-13
Helicopters (all)	1.08	1.05	1.07	1.04
C30 Landing craft	0.72	0.76	--	--
P30 Landing craft	--	--	0.58	--
P125 Landing craft	--	0.93	--	--
C150 Landing craft	1.84	1.94	1.84	--
LCM6 Landing craft	--	--	--	2.18
LCM8 Landing craft	--	--	--	2.76
LCU Landing craft	--	--	--	3.16

These results suggest that on the whole helicopters are slightly more cost effective than any advanced craft except the C150 and are less cost effective than conventional craft. The C150 is 75-85 percent more cost effective than the helicopter mix and 2-3 times as cost effective as other advanced landing craft. Some of these values are shown graphically on Figure 9.

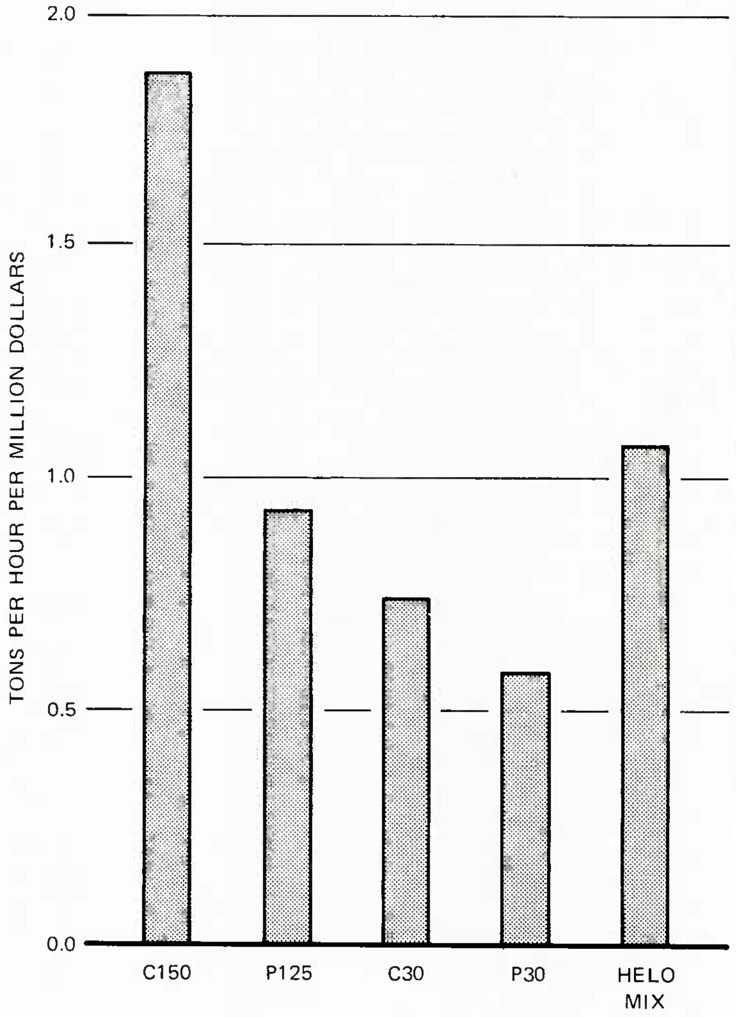

FIGURE 9 TONS PER HOUR PER MILLION DOLLARS FOR SELECTED DELIVERY VEHICLES (Delivery Vehicle Cost Only)

IV RESULTS OBTAINED WITH A HELICOPTER-LIFTABLE FORCE

In order to make a direct comparison of the performance of helicopters and landing craft, it was necessary to provide a situation in which the two types of delivery vehicles would be called upon to perform identical tasks. Helicopter tasks differ from landing craft tasks with the full MAF assault because much of the MAF cannot be lifted by helicopter, and because helicopters delivered their loads to points distant from the assault beach. Before comparable tasks could be assigned to helicopters and landing craft, it was necessary to establish a force that could be lifted by either delivery vehicle type and it was necessary to specify an environment that would equate the jobs performed by both. The first problem was overcome by designing a special helicopter-liftable force for this analysis. The second was overcome by specifying that the force be delivered directly to the rear of the assault beach from a stand-off distance of 25 nautical miles. To further assure comparability, only air-cushion-type landing craft were used in the investigations. For efficient use of the available carrying space, both C30 and C150 sizes were used.

The Force

The choice of force was difficult. The helicopter assault elements of Marine units are not intended to operate without early link-up with their follow-on elements. The follow-on elements contain most of the vehicles and heavy equipment, much of which cannot be lifted by helicopter. What was needed was a balanced military force, capable of combat action for a reasonable period, and so designed that all of its equipment could be lifted by helicopter. Rather than attempt an arbitrary modification of an existing Marine force, we hypothesized an HLF to meet the helicopter-liftable criterion. This force was modeled loosely after the Army's Airborne Division. The resulting force has the following characteristics:

Personnel (number)	13,300
Square feet of vehicles	254,000
Standard pallets for	
10 days of supply (number)	7,000
Special pallets (number)	250
Heavy-lift loads	
Vehicles (number)	257
Pallets (number)	250
Total tons	20,070

Such a force would obviously have some military drawbacks in terms of shock action, firepower, staying power and mobility compared with a standard division. Nevertheless, it is a division-size force designed for vertical assault and can be lifted in toto by either landing craft or helicopters. We have used it here solely as a vehicle for the comparison of the effectiveness of landing craft and helicopters. It should be considered a force designed to maximize helicopter effectiveness.

The Amphibious Fleet

Because the hypothesized HLF is less than half the size of a MAF and because it has drastically reduced amounts of vehicles and supplies, the number and types of ships required to lift the force are quite different from those selected for the MAF. Based on results of EMBARK* program runs, we determined that the force together with the designated mixes of craft and helicopters shown could be fitted into the mixes of ships listed in Table 11.

The mix of ships selected for Runs 31-3 and 31-4 is intended to provide the maximum opportunity for helicopter operations in Period II (1980 to 1985). At the other extreme, the ships selected for Runs 31-1 and 31-8 were intended to provide the maximum opportunity for efficient landing craft operations. In Run 31-6, six LKAs were substituted for the eight LPHs used in Runs 31-3 and 31-4. This substitution sharply decreased the number of helicopters that could be carried by the fleet, but increased the number of small landing craft that could be carried.

For each run, the numbers of helicopters and landing craft were selected to fit the force lift requirements and to maximize the use of shipboard carrying space. A larger number of heavy-lift helicopters was used in these simulations than in the MAF simulations because of the

* Jones, P. S., et al., op cit.

Table 11

SHIPS, HELICOPTERS, AND LANDING CRAFT
TO SUPPORT THE HLF, AND COSTS

Delivery Means	Run 31-1 (Landing Craft Only)	Run 31-3 (Helicopters Only)	Run 31-4 (Mixed)	Run 31-6 (Mixed)	Run 31-8 (Mixed)
Type of Ship					
LHA	6	6	6	6	6
LPD	15	7	7	7	15
LPH	--	8	8	--	--
LKA	--	--	--	6	--
Type of Craft					
C-30	75	--	67	103	75
C-150	36	--	20	20	36
Type of Helicopter					
CH-46	--	120	120	14	30
CH-53	--	60	60	60	60
HLF	--	45	45	45	45
10 Year Costs (millions of dollars)					
Ships	$1,971	$2,499	$2,499	$1,915	$1,971
Craft	734	--	522	684	734
Helicopters	--	1,194	1,194	759	825
Force	3,654	3,654	3,654	3,654	3,654
Total	$6,359	$7,347	$7,869	$7,012	$7,184

need to air-lift all 500 heavy loads without delaying the progress of the assault.

Summary Results

The amphibious assault simulations with the HLF were largely complete by Time: 10 hours. Therefore, comparative data were taken 6 hours after the start of the simulation* while operations were in full swing. At this time most of the vehicles had been delivered ashore and some of the pallets were ashore. The effects of the initial surge of deliveries had died out, but the delivery rate had not yet started to fall off. Summary results for the five HLF runs are listed in Table 12.

The most productive run is Run 31-4, a mixed run that favored helicopter performance by providing a large number of helicopters and ships with many helicopter loading positions, while also taking advantage of the landing craft capability of the ships in the mix. Performance in Run 31-8 was almost as good in all categories. The latter run was a mixed run that favored landing-craft performance by providing wells in all of the ships of the fleet.

Mixed run Run 31-6, did not yield performance as good as that observed in the other two mixed runs due to the substitution of LKAs for the more productive ships of the other mixes. The use of LKAs introduced three principal shortcomings: (1) LKAs have only limited capability for working with helicopters; (2) they carry only small landing craft (C30) instead of the more productive C150s; and (3) vehicle loading times are very much longer for LKAs than they are for well-type ships.

The landing-craft-only mix (Run 31-1) performed poorly because it was not able to take advantage of the helicopter capability. When helicopters were added, resulting in Run 31-8, performance was more than doubled. In Run 31-1 the 111 landing craft performed well individually, but as a whole could not compete with performance in the mixed runs.

The helicopter-only run (Run 31-3) was also less effective than the corresponding mixed run (Run 31-4). In Run 31-3, the craft carrying capability of the ships was not used. As a result, performance was only about 65 percent of that in the mixed run.

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* This corresponds to 10 hours after the assault started for the MAF operations described in Chapter III.

Table 12

SUMMARY RESULTS FOR HLF OPERATIONS AT TIME: 6 HOURS

	Run 31-1 (Landing Craft Only)	Run 31-3 (Helicopters Only)	Run 31-4 (Mixed)	Run 31-6 (Mixed)	Run 31-8 (Mixed)
Tons Delivered					
By landing craft	6,471	--	3,921	3,817	6,050
By helicopters	--	9,618	9,930	6,069	7,660
Total	6,471	9,618	13,851	9,886	13,710
Force-Time Effectiveness					
Landing craft	367	--	94	92	254
Helicopter	--	719	565	248	238
Overall	367	719	1,165	975	1,017
Time general unloading started (minutes)	405	330	202	290	196
Time to deliver 200,000 square feet vehicles (minutes)	552	355	245	356	248

In terms of force-time effectiveness, all of the mixed-run results were substantially better than runs employing either landing craft only or helicopters only.

Similar conclusions follow from analysis of the times required to deliver 200,000 square feet of vehicles and the times that general unloading started.

Time History of Deliveries

Figure 10 shows the cumulative tons delivered plotted against time for each of the simulated assaults with the HLF. The curves for the four runs with landing craft show the characteristic initial surge that results from scheduled waves and preloaded craft. Each curve has a reasonably constant slope from Time: 1 hour to Time: 7 hours, reflecting the period of uniform highly productive offloading. After 7 hours, the curves begin to exhibit shoulders reflecting the facts that ships start becoming empty so that the maximum offloading rate cannot be maintained, and that pallet handling proceeds more slowly than personnel and vehicle handling. For these simulations, pallet unloading is allowed to start after 200,000 square feet of vehicles have been offloaded from the ships. The all-craft curve shows a barely perceptible shoulder at about Time: 8 hours, after the start of pallet unloading. It does not form an additional shoulder until about Time: 20 hours.

The slope of the curves in Figure 10 indicates the steady-state delivery rates achieved with each mix of delivery vehicles. Mixed runs (Runs 31-4 and 31-8) clearly stand out. The two runs are even at Time: 3 hours and again at Time: 8.5 hours. In between, Run 31-4 has a slight advantage. Runs 31-3 (all helicopter) and 31-6 show about the same slope but Run 31-6 has the advantage of the surge due to preloaded craft. In Run 31-1 (all landing craft) results are poorer because of insufficient craft carrying capacity.

Figure 11 shows the tons of cargo delivered during each hour for each of the five simulated HLF assaults. The initial surge effect shows up strongly for those runs that have landing craft. After the initial surge the level of activity falls off while craft are being reloaded and then increases to a relatively constant level until at least Time: 7 hours. The four runs containing craft exhibit a periodic variation in deliveries that results from the tendency of craft to operate in waves. With the passage of time, the wave effect is spread out due to queueing at the ships. It is still evident at the beach every 2 to 3 hours.

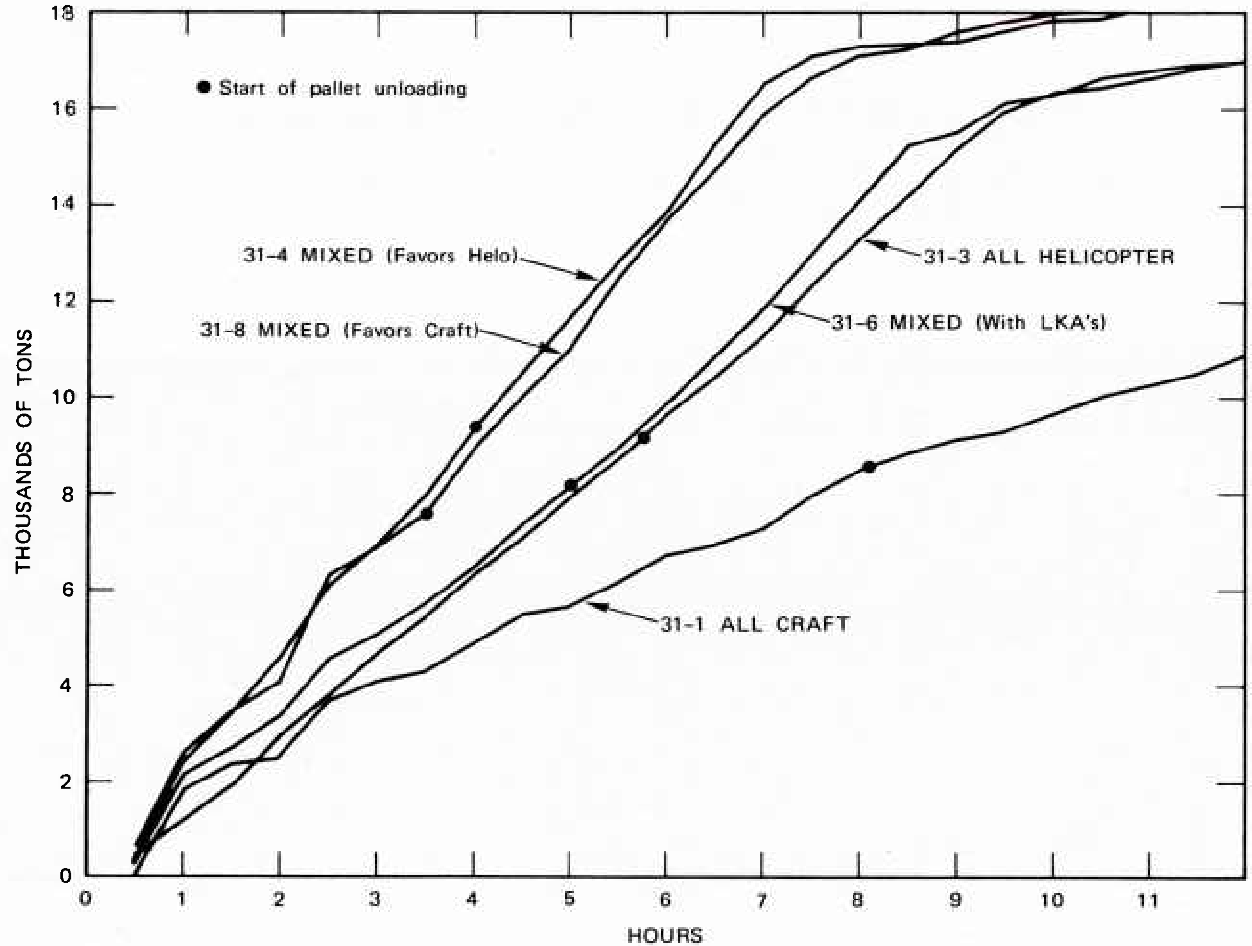

FIGURE 10 CUMULATIVE TONS OF CARGO DELIVERED AT END OF H HOURS, HELICOPTER-LIFTABLE FORCE

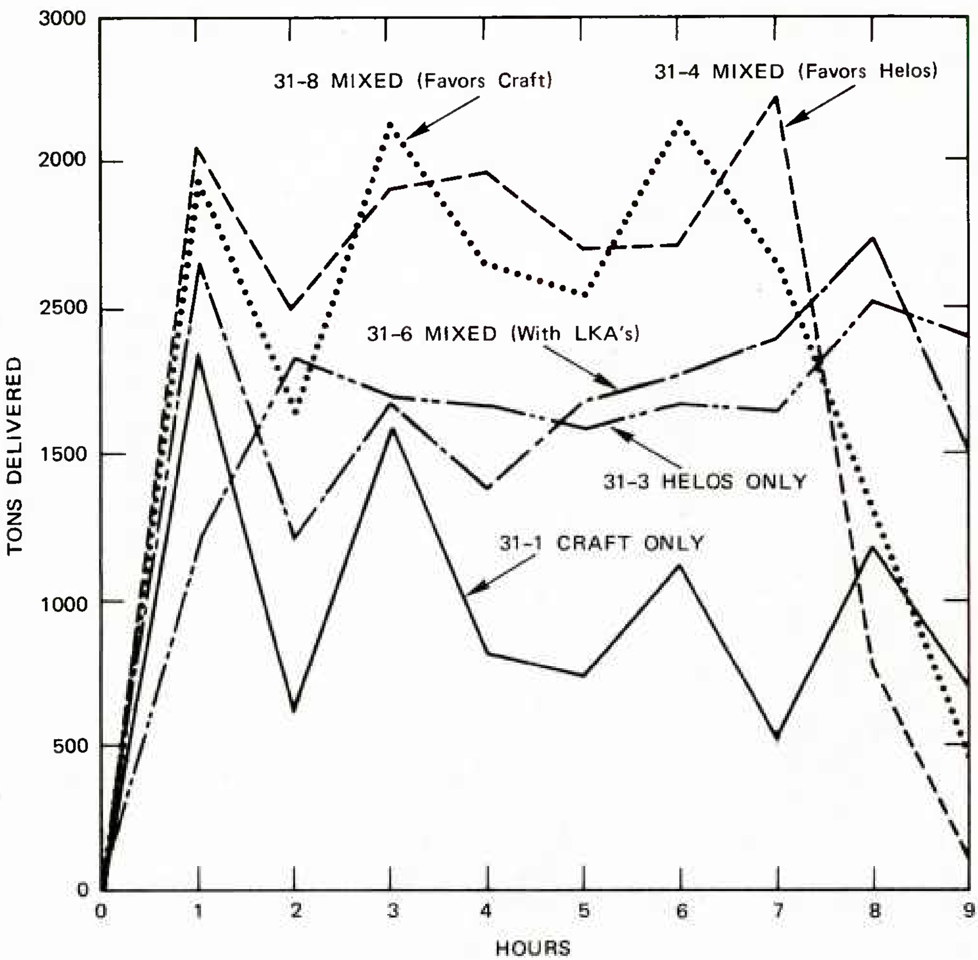

FIGURE 11 TOTAL TONS DELIVERED EACH HOUR, HELICOPTER-LIFTABLE FORCE

At 7 to 8 hours after the assault, there is another high point in the delivery curves. This is probably the result of a combination of the wave effect plus the fact that attrition rates decrease with time, as the assault force widens its perimeter and decreases the enemy threat to the delivery vehicles.

At the right side of Figure 11, all the hourly delivery values fall off, reflecting the shoulder of the cumulative delivery curve.

Figures 12 and 13 show the breakdown of tons of cargo delivered by helicopters and craft for each hour in Runs 31-4 and 31-8. The patterns are similar for both, though each has distinctive features. Craft deliveries show the expected initial surge and the wave effect; they fall off after about 4 hours, reflecting the longer time to load and unload pallets, and the presence of empty ships; and they continue for some time, reflecting craft cycle time and attrition delays.

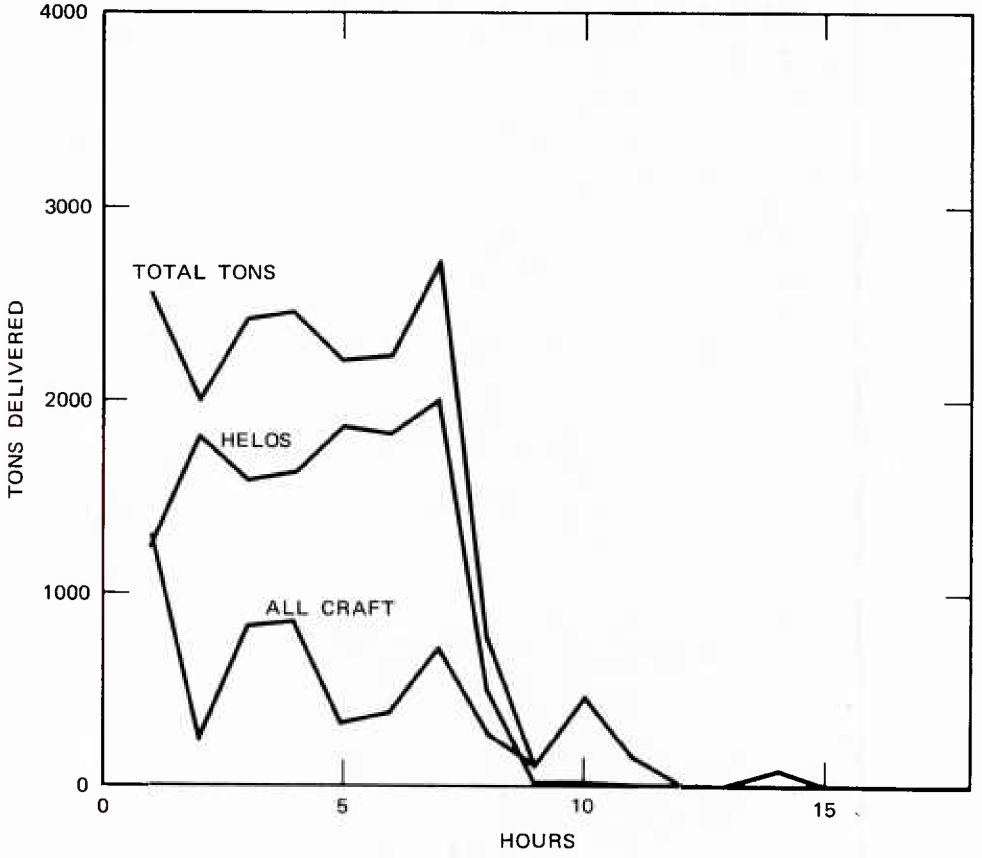

FIGURE 12 TOTAL TONS DELIVERED EACH HOUR BY TYPE OF DELIVERY VEHICLE, RUN 31-4

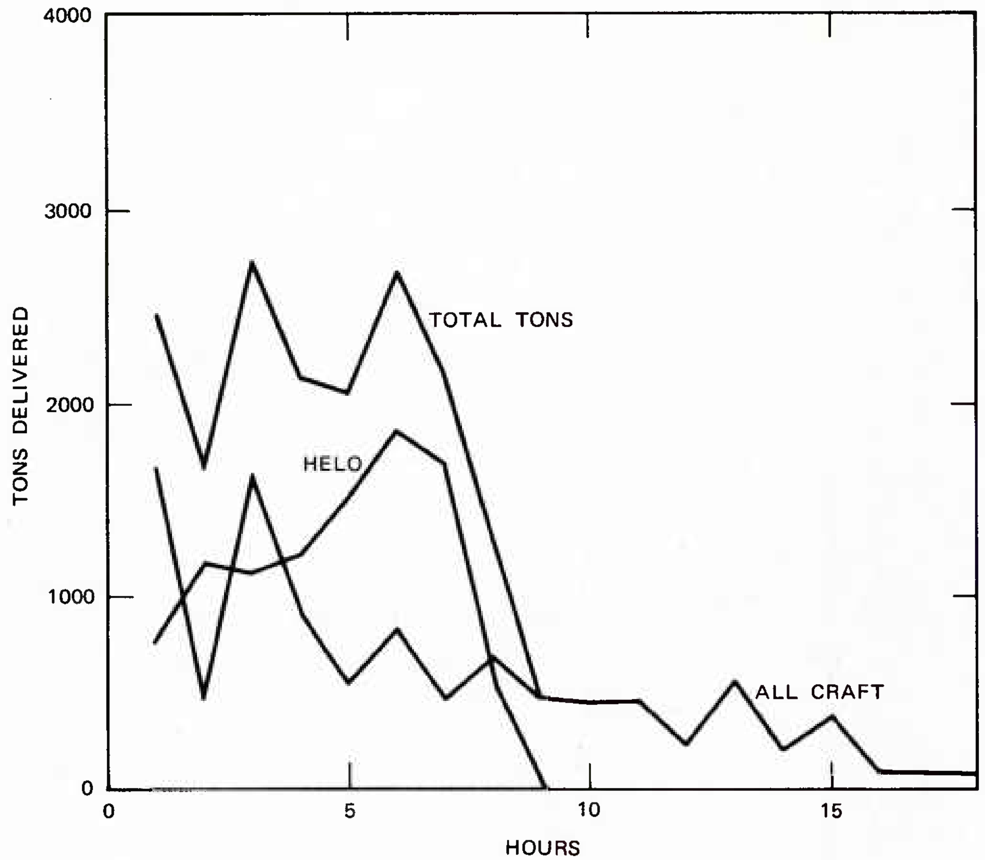

FIGURE 13 TOTAL TONS DELIVERED EACH HOUR BY TYPE OF DELIVERY VEHICLE, RUN 31-8

The tonnage delivered by helicopter is low at the beginning of the assault because of the light weight of personnel. Deliveries surge after Time: 4 hours with the start of pallet offloading. In these simulations, helicopters moved more pallets than landing craft, because more helicopters were available at the start of pallet offloading and because of the short helicopter cycle time. Helicopter offloading was largely complete by Time: 8 hours and dropped sharply, ending by Time: 10 hours.

Delivery Rates by Type of Delivery Vehicle

Based on data taken 6 hours after the start of the assault, the following delivery rates were observed for the two craft types and the helicopters:

Delivery Vehicle	Tons per Delivery Vehicle per Hour Run 31-1	Run 31-3	Run 31-4	Run 31-6	Run 31-8
C30	3.0	--	2.8	2.7	3.1
C150	24.9	--	23.0	17.8	21.6
Helicopters (all)	--	7.1	7.4	8.5	9.6

Rates for the C30 are fairly constant, and consistent with those obtained in the simulations with the MAF.

The rates for the C150 were also fairly constant, except for Run 31-6, in which the C150s had low productivity because of the long loading time at LKAs. Although there were a large number of C30s in this run, there was no indication that the C30s interfered with the C150s.

Helicopter productivity varied with the helicopter mix. Runs 31-3 and 31-4 used the same helicopter mix and the same fleet. The helicopters of Run 31-4 appear to have benefited from the presence of landing craft. A much larger fraction of HLH are used in Runs 31-6 and 31-8 with the expected increase in mean delivery rates. Run 31-6 suffers from the poor helicopter support provided by LKAs. The helicopter delivery rates for all runs are higher than those noted for the MAF runs, primarily due to the shorter delivery distance.

Tons of cargo per delivery vehicle load for the two landing craft types and the helicopters were as follows:

Delivery Vehicle	Tons per Delivery Run 31-1	Run 31-3	Run 31-4	Run 31-6	Run 31-8
C30	5.8	--	8.3	7.5	8.1
C150	50.0	--	50.2	50.5	48.4
Helicopters (all)	--	5.0	5.0	6.2	6.2

The average tons of cargo per landing craft load was about the same as observed for the MAF. An exception occurs for the C30 in Run 31-1 (landing craft only). In this run the C30 carried most of the low-density personnel loads. The C150s were less affected because they tended to carry large vehicle and cargo loads. The average load per helicopter reflects the helicopter mix. Note that the same loads were observed where the mixes were the same or almost the same.

Delivery Vehicle Productivity

The tabulation below summarizes the tons delivered per hour per 1,000 square feet of delivery vehicle during the delivery of the HLF. The results again indicate the superiority of the C150 over the C30. However, the helicopter mix is superior to either craft on a square-foot basis.

	Tons per Hour per 1,000 Square feet of Delivery Vehicle				
Delivery Vehicle	Run 31-1	Run 31-3	Run 31-4	Run 31-6	Run 31-8
C30	2.5	--	2.3	2.2	2.5
C150	6.2	--	5.9	4.4	5.4
Helicopters (all)	--	7.1	7.4	7.1	8.3

Cycle Times

Figures 14, 15, and 16 show the distributions of cycle times for the C30, C150 and helicopters respectively. The patterns in all three figures have much the same general shape as those found for the MAF runs. The principal difference is in the helicopter times, where the main spike occurs earlier because of the shorter travel distance.

The bimodality of the cycle time distributions for the landing craft results from disparate loading times for vehicles and cargo and from the influence of craft attrition. The influence of preloaded craft is less pronounced than it was for the MAF simulations because of the difference in force structure. The preboated loads for the HLF were lightweight vehicles whereas the MAF preboat loads were heavy LVTs.

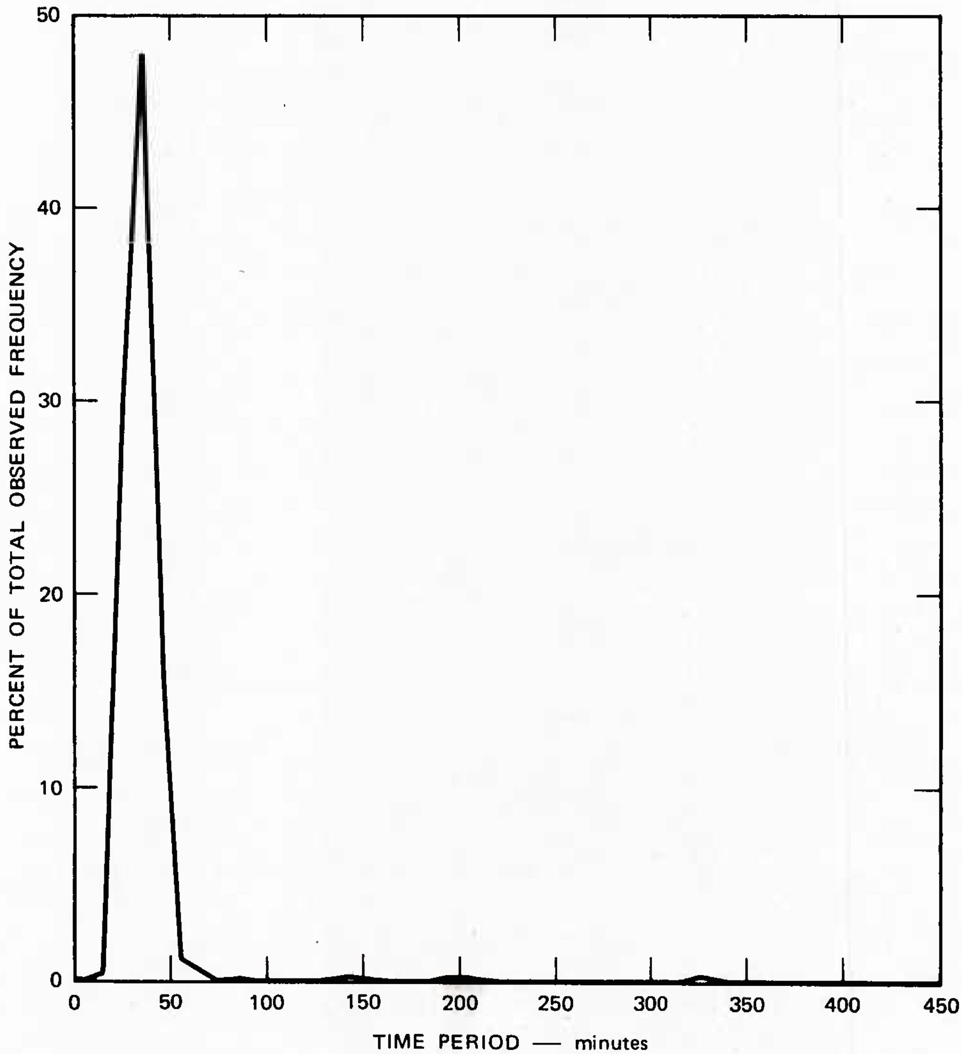

FIGURE 14 DISTRIBUTION OF CYCLE TIMES FOR HELICOPTERS AFTER 20 HOURS, RUN 31-8

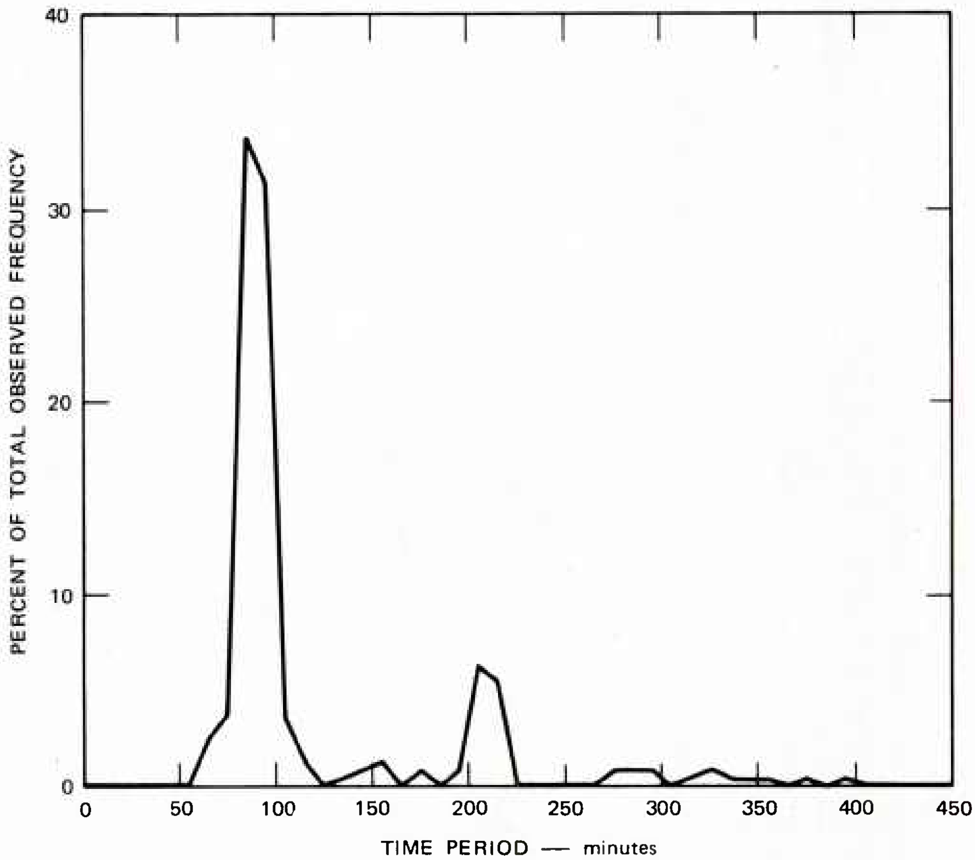

FIGURE 15 DISTRIBUTION OF CYCLE TIMES FOR C30 LANDING CRAFT AFTER 20 HOURS, RUN 31-8

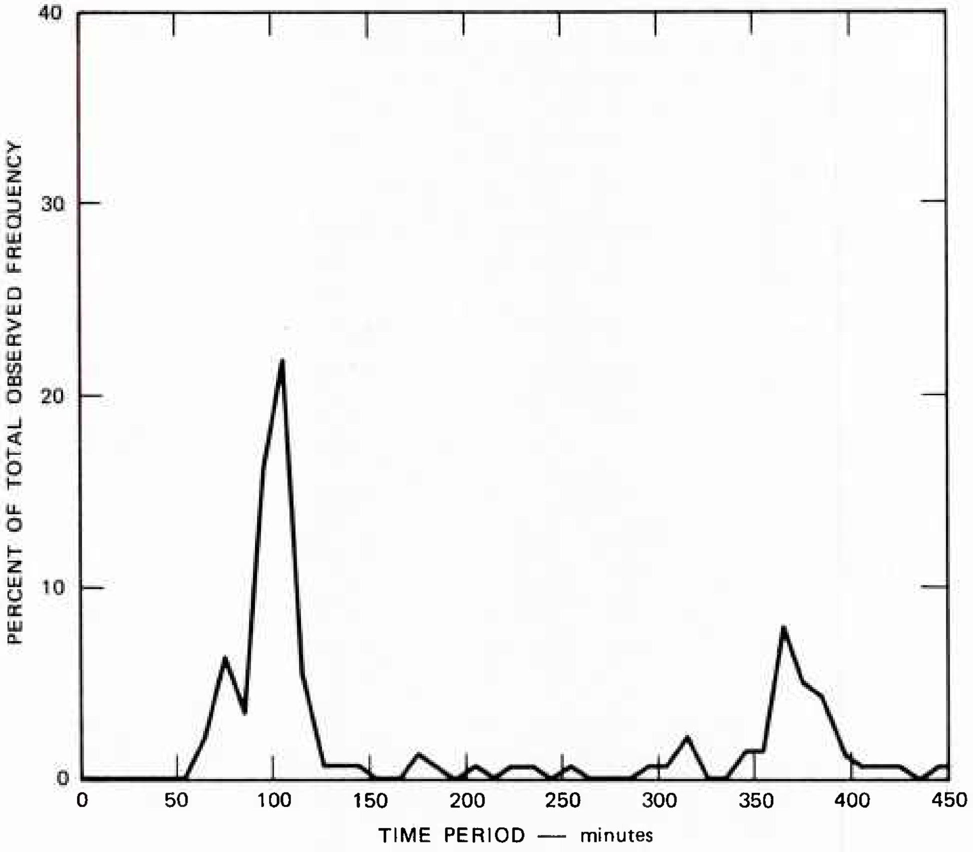

FIGURE 16 DISTRIBUTION OF CYCLE TIMES FOR C150 LANDING CRAFT AFTER 20 HOURS, RUN 31-8

Delivery of Load Types

The following tabulation shows the percent of the various load types that had been delivered after 6 hours of simulated operation time:

Load Type	Run 31-1 (Landing Craft Only)	Run 31-3 (Helicopters Only)	Run 31-4 (Mixed)	Run 31-6 (Mixed)	Run 31-8 (Mixed)
Personnel	78%	91%	98%	78%	97%
Vehicles	58	80	97	80	97
Pallets	--	--	47	8	34
Total cargo (tonnage)	33	48	77	48	69

These results emphasize the superiority of the two best mixed runs over the craft-only or helicopter-only runs.

Effectiveness/Cost Ratings

Effectiveness/cost ratings are listed below in terms of FTE and cargo delivery rate for the five simulation runs:

	Run 31-1 (Landing craft Only)	Run 31-3 (Heli-copters Only)	Run 31-4 (Mixed--Helicopters Favored)	Run 31-6 (Mixed--With LKA)	Run 31-8 (Mixed--Craft Only)
Total Assault Force cost (millions of dollars)	\$6,359	\$7,347	\$7,869	\$7,012	\$7,184
FTE	367	719	1,165	975	1,017
FTE/millions of dollars	0.058	0.098	0.148	0.139	0.142
Tons delivered/hour	1,124	1,603	2,304	1,948	2,285
Tons/hour/millions of dollars	0.177	0.218	0.293	0.278	0.318

By both measures, the mixed runs are substantially superior to the landing-craft-only and helicopter-only runs. The FTE measure favors Run 31-4 because of the shorter transit times of helicopters. Conversely, the tons-per-hour measure favors Run 31-8 because of the greater load-carrying capability of the C150. Tons/hour/cost values are displayed graphically in Figure 17.

Effectiveness/cost ratings can be prepared for all helicopters and all craft using only delivery vehicle costs with the following results:

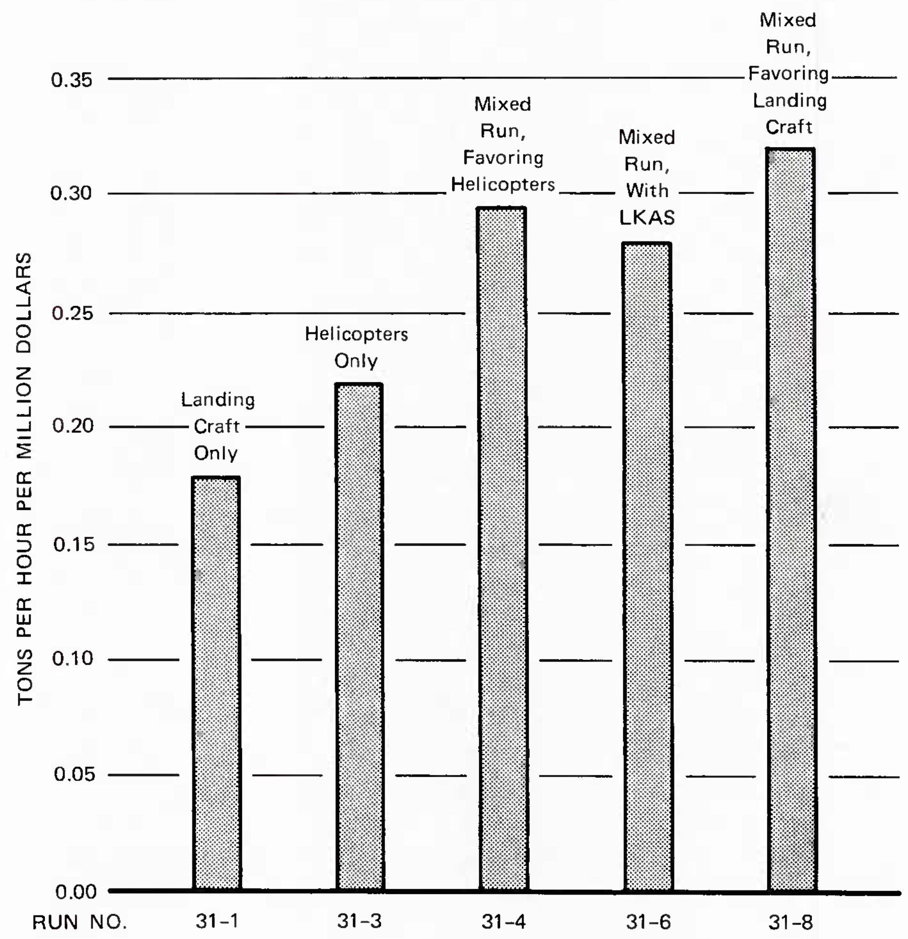

FIGURE 17 TONS PER HOUR PER MILLION DOLLARS OF TOTAL COST

	Run 31-1	Run 31-3	Run 31-4	Run 31-6	Run 31-8
Helicopters					
10-year life cycle costs (millions of dollars)	--	$1,196	$1,196	$759	$825
FTE	--	719	565	248	238
FTE/millions of dollars	--	0.60	0.47	0.33	0.29
Tons delivered/hour	--	1,603	1,655	1,012	1,275
Tons/hour/millions of dollars	--	1.34	1.38	1.33	1.55
Landing Craft					
10-year life cycle costs (millions of dollars)	$734	--	$522	$683	$734
FTE	367	--	94	92	254
FTE/millions of dollars	0.50	--	0.18	0.13	0.35
Tons delivered/hour	1,124	--	654	636	1,008
Tons/hour/millions of dollars	1.53	--	1.25	0.93	1.38

These results suggest that both helicopters and landing craft have higher FTE when working alone--a result due almost entirely to the distribution of cargo. As expected, the helicopters have a higher FTE effectiveness/cost ratio for Run 31-4 than any other mixed run. Similarly, the landing craft have a higher FTE effectiveness/cost ratio for Run 31-1. Both helicopters and craft show up well in Run 31-8 in terms of tons per hour per millions of dollars.

When the landing-craft mix is broken down by craft type, the results are very similar to those observed for the MAF. On the basis of FTE/cost, the C150 was slightly superior to the helicopter mix. On the basis of tons/hour/cost, it was superior by 20-50 percent. On both bases, the C150 was much superior to the C30.

Appendix A

RESULTS OBTAINED FROM PREVIOUS STUDIES

Appendix A

RESULTS OBTAINED FROM PREVIOUS STUDIES

Previous studies at SRI have provided results that are of interest in connection with this report. They provide both background and a starting point, and their principal conclusions exercised considerable influence on the conduct of the current study. Summarized below are aspects of each study, including conclusions of interest in follow-on work:

(1) S. Stidham, Jr., "Systems Analysis of Amphibious Assault Craft; Preliminary Analysis of Cargo Spaces for Assault Craft," Stanford Research Institute, Menlo Park, California, October 1966.

This report describes a technique for dimensional fitting of individual items of equipment into a craft cargo area and an analysis of optimum craft cargo well sizes as a function of the sizes of equipment items in a Marine Force. The dimensional fitting routine described is an integral part of the PREBOAT program* and also functions to compute individual craft loads in NWL's amphibious assault simulation program (STS-2). The report also analyzes a range of craft cargo well sizes and determines a set of optimal sizes. These sizes were subsequently used in requests for preliminary craft designs and are presently incorporated in the latest AALC designs.

(2) E. H. Means and D. E. Vaughn, "Marine Assault Forces and Amphibious Operations Plans (U)," NWRC/LSR-RM42, Stanford Research Institute, Menlo Park, Calif., August 1967 (CONFIDENTIAL).

This work derived the detailed organization of a Marine Amphibious Force MAF) for the mid-term. This force organization was used in all subsequent analyses, including the

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* The PREBOAT program is described in (3).

simulations of amphibious assault activities. The force is on cards and tape in computer processable form.

(3) P. S. Jones, J. I. Steinman, A. A. Lynch, Jr., "Analysis of Present Craft in Future Environments," Stanford Research Institute, Menlo Park, California, and Naval Weapons Laboratory, Va., February 1969.

This work evaluates the effectiveness of presently available amphibious landing craft under a variety of conditions. An examination is made of the sensitivity of the effectiveness measures to Marine force composition, embarkation procedures, fleet stand-off distance, sea state, landing craft attrition and changes in beach operations. Results of this analysis provided a base with which to compare advanced craft effectiveness as well as indicating the factors to which performance is sensitive.

In addition to a presentation of results, the methodology developed for the AALC systems analysis is described in detail. Included are details on computer programs which: preload equipment onto craft (PREBOAT), embark the Marine force on the ships of the amphibious fleet (EMBARK) and simulate an entire amphibious assault (STS-2). Programs were developed at both SRI and NWL and the analysis is a joint effort.

Some conclusions are:

- Landing craft performance is extremely sensitive to fleet standoff distance, sea state, and landing craft attrition. It is important that the maximum number of craft be carried. Therefore, craft carrying space should be fully utilized to transport craft.

- Landing craft performance is relatively insensitive to the precise composition of the force carried, or to the percent of the force delivered by craft. It is also insensitive to minor changes in beach operations.

- During the general unloading phase, craft performance is very sensitive to cargo handling rates at the ships and at the beach, and also to beach width.

(4) D. G. Jorgenson, "Cost Model and Cost Estimates," Stanford Research Institute, Menlo Park, Calif., March 1969.

This work established an algorithm for the estimation of the costs of present and projected landing craft, and applied the algorithm to all of the craft being examined in the AALC program.

(5) M. J. Nielsen, "Systems Analysis of Amphibious Assault Craft; Vehicle Test Loading Results," NWRC/LSR-RM-51, Stanford Research Institute, Menlo Park, California, April 1969.

In May 1968 SRI conducted a series of vehicle loading tests at Camp Pendleton, California. These tests provided basic data on times to load vehicles onto craft in well deck ships and also times to unload these same vehicles on hard sand. Analysis of the results yielded specific loading and unloading times as a function of vehicle size and whether or not it was towing a trailer. Information on efficient loading and unloading procedures was also developed. The craft loading and unloading rate algorithm used in STS-2 is based on this work.

(6) A. R. Grant, "Vulnerability of Land Craft," NWRC/LSR-RM-52, Stanford Research Institute, Menlo Park, Calif., April 1969.

This work derives an algorithm for estimating the vulnerability of a landing craft in a hostile amphibious environment, and applies the algorithm to existing and proposed craft to calculate expected attrition rates.

Among the principal conclusions are that the vulnerability of a craft is governed by its size, shape and speed, by the size, shape and toughness of its vulnerable parts, and, most importantly, by the level of effort of the forces attacking it.

(7) J. I. Steinman, A. R. Grant, P. S. Jones, M. J. Nielsen, "Comparison of Preliminary Designs of Advanced Landing Craft," NWRC/LSR-RM-56, Stanford Research Institute, Menlo Park, Calif., December 1970.

This work reports the results of computer simulations, which provide the basis for a comparison of preliminary advanced craft designs as well as the selection of designs for future work. The STS-2 program system, developed by NWL and SRI is the primary source of data. Also included in this report were

selected results using SRI's GAMUT simulation program. GAMUT is programmed in GPSS and examines variations in parameters not feasible using the STS-2 program.

Conclusions are:

- Advanced amphibious assault landing craft provide better results than conventional landing craft at a 5 nautical mile standoff distance with respect to both effectiveness and cost effectiveness. At a 25 nautical mile standoff distance, this difference is more pronounced; about a two-to-one advantage for advanced craft.

- The most effective landing craft were found to be the:

  - 30,000-lb-payload air cushion craft,
  - 125,000-lb-payload planing craft,
  - 150,000-lb-payload air cushion craft,
  - 320,000-lb-payload planing craft.

- Among other craft examined, the LCA was superior to the LARC-15, but is still much less effective than any of the advanced landing craft.

- Based on a number of GAMUT runs the following conclusions were reached:

  - LVT's can be delivered from long standoff distances by either craft or ship. Each mode has its special advantages and problems.
  - Operation of the advanced landing craft in waves did not greatly reduce their effectiveness.
  - At least 24 craft unloading positions (at the beach) should be provided for a MAF-size force. Fewer positions result in excessive craft queueing offshore.
  - Assault effectiveness was found to be sensitive to standoff distance, as is the case for present craft. Force-time effectiveness at 25 nautical miles was found to be about 70% of that for a 5 nautical mile standoff.

- Assault effectiveness was found to be relatively insensitive to increases in ship interval.

- Sending ACV's inland to deliver their cargo, rather than discharging it directly behind the beach, was found to decrease the force-time effectiveness, but still might be advantageous if rapid delivery is important.

- Minor variations in the numbers of craft in a mix was found to have little effect on force-effectiveness, as long as the available space for craft in the ships was filled up.

- During general unloading, only about half the available craft can be effectively used, and high craft speeds become less important.

Appendix B

PRINCIPAL CHARACTERISTICS OF THE FORCES USED

Appendix B

PRINCIPAL CHARACTERISTICS OF THE FORCES USED

Type of Unit	MAF Personnel	MAF Vehicles	HLF Personnel	HLF Vehicles
Headquarters	1,586	205	640	203
Infantry	11,244	708	7,200	1,395
Amphibious Tractors	1,266	329	--	--
Artillery	3,436	1,076	1,610	524
Armor	656	215	--	--
Reconnaissance	603	86	630	230
Aviation	omitted*		350	92
Engineer	1,111	492	570	233
Communications	672	228	550	226
AT	392	63	--	--
Service Units	6,668	1,322	1,750	507
	27,634	4,724	13,300	3,410

Principal Vehicles and Weapons	MAF	HLF
Howitzer, 105 mm	54	54
Howitzer, 155 mm	18	--
Gun, 155 mm	6	--
Howitzer, 8"	6	--
AT weapon	15	--
Tank, 90 mm	62	--
Truck, 1/4-ton	609	884
Truck, 1/2-ton	289	439
Truck, 3/4-ton	179	--
Truck, 2 1/2-ton	350	225
Truck, 5-ton, all types	268	619
Truck, amphibious	67	--
Amphibious tractor	228	--
Trailer, 1/4-ton, all types	589	517
Trailer, 3/4-ton, all types	111	463
Trailer, 1 1/2-ton, all types	254	--
Tractor	25	--
Other vehicles	1,594	209
	4,724	3,410

* The aviation elements of the MAF including some 6,700 troops and 1,500 vehicles are not included in the force to be delivered, although space is provided to lift the aviation elements on board the shipping. This practice which started with the STS-2 model, was carried over into the GAMUT model to ensure comparability.

Appendix C

SIMPLIFIED MATHEMATICAL DEVELOPMENT OF FORCE-TIME EFFECTIVENESS

Appendix C

SIMPLIFIED MATHEMATICAL DEVELOPMENT OF FORCE TIME EFFECTIVENESS

Given:

N_i = strength of Force i, where i = 1, 2

F_i = fire power of Force i

K_i = effectiveness of fire power of Force i

$A_i = \Delta N_i$ = attrition rate for Force i (casualties in unit time).

Then for two opposing forces, in contact,

$$A_1 = \Delta N_1 = -K_2 F_2$$

and

$$A_2 = \Delta N_2 = -K_1 F_1 \quad .$$

That is, the attrition rate for a force is proportional to the fire power of the opposing side. But the absolute attrition rate is of less significance than the relative rate, or the fractional loss rate. A unit of 100 men sustaining 30 casualties in unit time has obviously been hurt more severely than a unit of 1,000 men. For the 100-man units the casualty rate is 30 percent, but it is only 3 percent for the other. What is needed, therefore, is the percentage rate, defined as:

$$P_i = 100 \frac{A_i}{N_i}$$

then

$$P_1 = \frac{100\ A_1}{N_1} = \frac{-100\ K_2F_2}{N_1}$$

$$P_2 = \frac{100\ A_2}{N_2} = \frac{-100\ K_1F_1}{N_2} \quad .$$

For units that remain in contact the comparison of the percentage loss rates is a prime measure of the effectiveness of one force in dealing with the other:

$$P_1 = \frac{-K_2F_2}{N_1} \cdot \frac{N_2}{-K_1F_1} = \frac{K_2}{K_1} \cdot \frac{(N_2F_2)}{(N_1F_1)} \quad .$$

This says that the percentage loss rate suffered by each unit is inversely proportional to the product of its strength and firepower, and directly proportional to the product of the strength and firepower of the opposing force, and constitutes the theoretical basis for the force-time effectiveness used in this study.

The above analysis was intended primarily to illustrate the method of approach. A great deal more has been done with the method, and the literature on the subject is extensive. A few of the expandable features can be mentioned. Firepower is a function of residual strength, residual supporting fire and other factors. The firepower strategies of the two sides should be given. Application of firepower has a direct effect on the opposing firepower as well as on the opposing strength. Not all members of the force should be considered in the strength, but mostly the maneuver elements that are in contact. The firepower effectiveness of each side is probably not the same and varies with the weapon type, the environment, and the target. All these factors, and more can be included in the formulation of the initial equations.

The handling of the equations thereafter is the same as the above and yields the same result, that the percent of attrition is inversely proportional to the product of a unit's strength and firepower.

Appendix D

DESCRIPTION OF THE MODEL

Appendix D

DESCRIPTION OF THE MODEL

General

Data for the comparisons between helicopter and landing craft performance were generated by the SRI GAMUT model, which is a family of ship-to-shore simulations written in GPSS/360 (General Purpose Simulation System) and run on an IBM 360 computer. It simulates all of the principal actions in an amphibious assault, including the activities of LVTs, landing craft, helicopters and ships. It assesses attrition and monitors the status of offloading and of delivery to the shore and collects statistics useful in analysis. Considerable flexibility is built into the model so that such items as standoff distance, craft characteristics, LVT delivery mode and others can be changed easily.

The input to the model consists of modified results from the EMBARK* model, craft characteristics, operational characteristics, and environmental conditions. EMBARK results are modified primarily to reduce the level of descriptive detail about the Marine force. The force is described in terms of square feet of vehicles, number of personnel, and number of pallets of general unloading cargo.

The GAMUT family of models consists of one consolidated program and a number of subsets that have been modified to run separately if desired.

These include:

- A landing craft operation section, which is the main part of the model;
- A helicopter operations section, which is called GAMUT-H when run separately;

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* Jones, P.S., et al., op. cit.

- A landing ship operations section, which is called GAMUT-S when run separately;

- A beach operations section, which is called GAMUT-B when run separately.

There is also a version of the craft operations section, called GUSIM, that treats only the unloading of pallets during general unloading and does so in somewhat greater detail than the consolidated program.

To simplify the handling of the 90 or more different pallet types used by an MAF, an SRI-developed clustering analysis* was used to group, or cluster, the pallets into a smaller number of types according to their essential characteristics. For the detailed consideration of pallets, eight separate pallet types were used. For other considerations, as in the consolidated GAMUT model, the eight types were further consolidated into three types as indicated by the clustering analysis. These breakdowns are considered adequate for the analysis of landing craft and helicopter activity.

The landing-craft operations section simulates the actions of each craft as it goes to a ship, picks up a load, moves to the beach, finds an unloading position, unloads and returns to the boat pool or to another ship. Three types of landing craft are provided for and six different load types, each of which has its own unique handling requirements. Craft delivery is to the shoreline for displacement craft, and to a temporary dump in the rear of the beach for ACVs. The inland delivery distance is an input to the program.

The helicopter section simulates the operation of up to three types of helicopters. The helicopters perform their assault missions. After the assault units are delivered to their objective areas, all or some of the helicopters are made available to assist with the continued delivery of vehicles and cargo ashore. In general, helicopters are given loading preference at LHA- and LPD-type ships that can offload simultaneously by helicopter and landing craft; however, this is an input and can be varied. Helicopter loads are limited to vehicle and cargo types that helicopters can lift. Helicopter delivery of vehicles and cargo can be made to the LSA, to a separate operations area, or to the beach. This facilitates comparison with ACV craft delivering cargo inland and PLH craft deliveries

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* See D. J. Hall et al., "PROMENADE, An Improved Interaction-Graphics Man/Machine System for Pattern Recognition," RADC-TR-68-572, Stanford Research Institute, Menlo Park, California, 1969.

at the beach. Statistical data on helicopter delivery are maintained separately from data on delivery by other means.

The landing ship operations section simulates LST operations, keeps track of vehicles, personnel, and pallets delivered by LSTs, and segregates the data from data on cargo delivered by other means for the purposes of statistical reporting. The number of causeways and their installation time can be varied.

The beach operations section maintains a running inventory of LVTs, other vehicles, personnel, and pallets located at the beach. It monitors receipts, assigns attrition to the current contents of the beach, and sends LVTs, personnel and other vehicles out of the beach area to an unspecified destination. It sends pallets out of the area to the LSA, and monitors deliveries to that area by truck or by helicopter. This subset of the program is to be expanded to reflect greater detail in cargo handling at the beach.

Principal Program Features

- The LVTs are delivered either by landing craft or by ship as one of the first actions after the start. Vehicle and personnel deliveries by craft are delayed so as not to overlap with LVT delivery. Helicopter deliveries are not delayed. When LVTs are delivered by ship, any ship may be used, but usually LSDs are used, as they carry the maximum number in the fewest ships.

- Vehicles are treated on a square foot basis, in nominal units of 100 square feet. For vehicles not loaded on LSTs, this value is very close to the actual average area of a vehicle. The nominal 100-square-foot vehicle has an average weight of 7,500 lbs, based on MAF serial data. The same procedure is used for vehicles loaded on LSTs except that the average vehicle weight is higher.

- Vehicle loading in craft is computed by use of utilization factors taken from the STS-2 programs, based on a detailed fitting program. The cargo area available in the craft is reduced by the utilization factor, and the result represents the vehicle areas to be loaded, taken in units of 100 square feet.

- Personnel are offloaded in two ways, either as purely personnel serials, or accompanying vehicles in vehicle serials. Purely personnel serials are loaded into the smallest craft that will accept them. Personnel who accompany vehicles are not considered to occupy space--they are assigned on an average rate of 5 men per 100 square feet of vehicle.

- There are a number of directed personnel serials for craft, delivered in the first few hours of the problem. Thereafter, personnel accompany vehicles until all vehicles are offloaded from a ship, after which any remaining personnel are offloaded as personnel serials.

- Helicopters concentrate 75% on delivery of personnel until the assault elements are offloaded. Thereafter, vehicles are offloaded, accompanied by personnel until the vehicles are gone. Residual personnel are offloaded by craft, except from LPHs.

- Pallet loads are assigned to craft and helicopters based on precomputed capacities, after a consideration of weight, square, cube and stacking capability for each pallet type. Pallet types may be mixed on craft, but provision is not made for this on helicopters.

- Attrition is considered for craft and helicopters three times during each cycle, once on the way in, once while unloading, and once on the way back to the ships. Separate attrition rates are assigned to each type of delivery vehicle for each of the three phases. The attrition rate is applied by the drawing of a random number. If a craft is affected by attrition, another random number is drawn which is used to enter a time-out-of-action table to determine how long that status is to apply. If the time-out-of-action exceeds a specified threshold, the craft (or helicopter) is considered killed and is removed from the problem. Cargo aboard craft killed on the way to the beach is considered lost. Cargo aboard craft killed during unloading is not lost. Attrition rates decrease exponentially with time, reflecting the decrease in enemy activity as the operation progresses.

- The ballast condition of well-type ships is taken into account. Planing craft are assigned to well-type ships that are ballasted down. If no planing craft are available, a delay occurs while the ship ballasts up to a dry well and then ACV craft are assigned. Similarly, a ship with a dry well seeks ACV craft. If none are available, the ship ballasts down and then accepts planing craft.

- Delay is allowed at the start of the problem for the offloading of craft that are deckloaded on LKAs.

- Preboated craft are handled in the program just the same as any other craft with the exception that loading time is not assessed for the first trip. All craft are considered preloaded, except for those that are deckloaded on LKAs.

- Landing craft and helicopter operations are essentially independent of each other, as in real life, but they interact by competing for loads on ships that have a dual capability.

- A constraint can be placed on helicopter loads by specifying the number or percent of the different load types they are allowed to take. This accounts for loads that are beyond the capabilities of helicopters.

- Wave formations for craft are allowed for. All craft leaving a ship to go to the beach join either an ACV or a planing-hull wave. These waves are released by the program when they reach a specified size or upon the passage of a set length of time. Both the wave size and the maximum wait time are program inputs. Wave requirements can be eliminated by making the maximum wait time zero, in which case craft never wait for a wave.

- Wave sizes and wait times are different for LVT loads than for other vehicle loads, and are changed again for general unloading.

- No wave-forming mechanism is provided for helicopters.

Inputs to GAMUT

Ship Inputs

Ship type and number

Distance from shore

Distance from boat pool

Number of vehicles, pallets, personnel, LVTs

Loading positions open for landing craft and helicopters

Loads available to helicopters

Craft and helicopter preferences

Loading rates by load type

Ballasting times

Number of directed personnel serials

Landing Craft and Helicopter Inputs

Craft type and number

Craft width

Nominal payload

Nominal speed

Maintenance time

10-year cost

Cargo area

Capacity by load type

Load preference

Maneuver times at ships and beach

Probability of attrition

Time out of action if attrition occurs

Payload vs speed function

Utilization function for vehicle loads

Unloading spot preferences

Number of deckloaded craft

Miscellaneous Inputs

Number of causeways

Initial delay for causeways

Delay between adjacent causeways

LST unloading rate

LST maneuver times

Standoff distance additive

Ship interval distance multiplier

Distance inland to LSA

Distance inland to helicopter operations area

Load weights by type (non-LST loads)

Load weights by type (LST loads)

Miscellaneous Inputs (Concluded)

LVT delivery mode

Delay for LVT delivery

Number of LVTs

Wave sizes for craft

Wave wait times for craft

Beach departure rates by type load

Beach attrition rates

Outputs by GAMUT

"Tailored" Output for Selected Periods

Number and types of landing craft

Number and types of helicopters

Special situation

Operations summary

Delivery data

"Standard" Output for Selected Periods

Time history of deliveries

Time spent in various activities

Current contents of landing craft and helicopters

Attrition record

Beach Inventory status

Deliveries to LSA

Cycle times

Ship status

Utilization of ships

Miscellaneous

Operation of the Program

Preliminary Actions

Set random number starters.

Record selected input data in output form.

Generate load preference matrices.

Modify standoff distance and ship interval.

Generate landing craft and helicopters.

Generate ships.

Process ships, landing craft and helicopters for start of operations.

Ship Operations With Landing Craft

Offload LVTs by craft or by direct delivery.

Offload directed personnel serials, if any.

Offload other load types in accordance with priorities.

When craft are needed:

- Call craft to get load; ballasts if necessary;
- Check for firm allocation of load;
- Release next ship to get craft;
- Wait for loading to be complete;
- Repeat.

Ship Operations With Helicopters

Call for helicopters for load type specified by priority.

Check for firm allocation of loads.

Release next ship to get helicopter.

Wait for load to be complete.

Repeat.

Craft Operations

Craft called by ship checks on availability of load.

Return to boat pool if no load.

Decrease ship contents, by type of load.

Increase offloading, by type of load.

Record load.

Record time loading, moving and maneuvering time at the ship.

Join wave for move to beach.

Move to beach.

Record waiting and movement time.

Select unloading position.

Wait to unload, and unload.

Record times.

Record delivery data by type.

Return to boat pool.

LST Operations

Wait for installation of causeways.

Maneuver to causeways.

Unload vehicles and personnel.

Receive trucks for unloading of pallets, if any.

Unload pallets.

Release causeway.

Release next ship to come to causeway.

Record deliveries.

Record times.

Beach Operations

Monitor receipt of loads by type.

Assign attrition to all types of loads.

Maintain running inventory of all load types at beach and at LSA.

Record movement out of beach area by all load types.

Sample GAMUT Output

The following pages contain selected results from Run 31-8, including the summary pages and the detailed delivery histories, which are the results of principal interest. The headings on the delivery histories have been inserted by hand, as these are not provided for in GPSS.

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ANALYSIS OF LANDING CRAFT ACTIVITY

PROGRAM GAMUT

RUN NO. 31 - 8

	TYPE 1 CRAFT	TYPE 2 CRAFT	TYPE 3 CRAFT	ALL CRAFT
CRAFT	C30	P125	C150	
NUMBER	75		36	111
SPEED(KTS)	50	35	50	
CAPACITY	300C0	125000	150000	
	TYPE 4 HELI	TYPE 5 HELI	TYPE 6 HELI	ALL HELI
HELICOPTER	CH46	CH53	HLH	
NUMBER	30	60	45	135
SPEED(KTS)	130	150	90	
CAPACITY	4900	8600	26200	

SPECIAL SITUATION AT 20 HOURS
A LIGHT DIVISION FORCE IS USED FOR THIS SERIES OF SIMULATIONS, CONSISTING OF

TOTAL TROOPS	13300
SQ FT OF VEHICLES (100'S)	2540
PALLETS	7250

THIS RUN INCLUDES BOTH LANDING CRAFT AND HELICOPTERS IN A MIX OF SHIPS TAILORED TO MAXIMIZE CRAFT PERFORMANCE
THERE ARE 6 LHA'S AND 15 LPD'S

STANDOFF DISTANCE, NAUTICAL MILES	25
SEA STATE	3
BEACH SLOTS, ACV'S	16
BEACH SLOTS, PLH'S	16

GENERAL UNLOADING STARTS AFTER 80% OF VEHICLES HAVE BEEN OFFLOADED FROM SHIPS
ATTRITION RATES DECREASE EXPCNENTIALLY WITH TIME

RUN NO. 31 - 8

ACTIVITY SUMMARY AFTER 20 HOURS

ACTIVITY	TIME
VEHICLE LOADING STARTED	1
FIRST VEHICLE DELIVERED	33
80% OF VEHICLES DELIVERED	248
GENERAL UNLOADING STARTED	196
90 PCT OF PALLETS DELIVERED	
LOSSES DURING DELIVERY	
VEHICLES (100'S SQ FT)	61
PALLETS	33
PERSONNEL	251
LOSSES AT BEACH	
VEHICLES	74
PERSONNEL	445

RUN NO. 31 - 8

SELECTED RESULTS AFTER 20 HOURS

	TYPE 1 CRAFT	TYPE 2 CRAFT	TYPE 3 CRAFT	SHIPS	HELI-COPTERS	TOTAL
DELIVERIES						
LVT'S						
VEHICLES	295		1067		1116	2478
PALLETS	928		2009		4280	7217
PERSONNEL	950		6090		6069	13109
TONS	2275		7890		9957	20122
TONS/HOUR	113		394		497	1006
MAX RATE	304		1370		1334	2484
FORCE EFFECT	51		1081		1190	2322
PCT, F.E.	2		46		51	
OVERALL FORCE EFFECTIVENESS						6867
CRAFT DATA						
TRIPS	241		137		1544	378
TRIPS/CRAFT	3		4		11	3
TONS/CRAFT	28		198		68	83
CYCLE TIME	128		218		37	161
LOSSES	11		4		2	

TIME HISTORY OF DELIVERIES, ALL MEANS

MATRIX HALFWORD SAVEVALUE 9

ROW	Deliveries: Type 1 Pallets	Type 2 Pallets	Type 3 Pallets	Vehicles	LVTs	Personnel	Total Force Effect-iveness	Craft in Total	Total Pallets	Tons (10s)	Pallets in Last 30 min.	Tons in Last 30 Mins	Pallets Off-Loaded	Tons Per Hour	Pallets on Craft	Vehicles Off-Loaded	Over-all Force Effect-iveness	Time in Mins.
1	0	0	0	13	0	2321	0	0	0	33	0	0	0	0	0	0	0	30
2	0	0	0	453	0	5928	8	0	0	244	0	211	0	2440	0	776	27	60
3	0	0	0	674	0	7101	8	2	0	345	0	101	0	2300	0	1164	27	90
4	0	0	0	815	0	7687	33	0	0	409	0	64	0	2045	0	1415	90	120
5	0	0	0	1311	0	9419	33	0	0	621	0	212	0	2484	0	1559	90	150
6	0	0	0	1460	0	9696	91	0	0	683	0	62	0	2276	0	1826	232	180
7	0	0	0	1639	0	9957	91	0	0	758	0	75	175	2165	175	2067	232	210
8	174	0	0	1921	0	10867	177	0	174	897	174	139	618	2242	444	2202	441	240
9	408	0	0	2110	0	11297	177	4	408	1001	234	104	1167	2224	759	2356	441	270
10	783	0	0	2262	0	11467	285	0	783	1102	375	101	2047	2204	1264	2532	700	300
11	1449	0	0	2422	0	12552	285	0	1449	1246	666	144	3087	2265	1638	2540	700	330
12	2463	0	0	2462	0	12859	418	2	2463	1371	1014	125	4230	2285	1767	2540	1017	360
13	3441	0	0	2477	0	12859	418	30	3441	1478	978	107	5100	2273	1659	2540	1017	390
14	4308	0	24	2477	0	13109	554	30	4332	1587	891	109	5729	2267	1397	2540	1342	420
15	4849	0	78	2477	0	13109	554	35	4927	1678	595	91	5877	2237	950	2540	1342	450
16	5179	0	80	2478	0	13109	690	44	5259	1714	332	36	5877	2142	618	2540	1667	480
17	5197	0	92	2478	0	13109	690	50	5289	1724	30	10	6090	2028	801	2540	1667	510
18	5227	0	146	2478	0	13109	826	52	5373	1761	84	37	6303	1956	930	2540	1992	540
19	5257	0	176	2478	0	13109	826	63	5433	1784	60	23	6445	1877	1012	2540	1992	570
20	5348	0	196	2478	0	13109	962	63	5544	1806	111	22	6516	1806	972	2540	2317	600
21	5419	0	196	2478	0	13109	962	63	5615	1814	71	8	6641	1727	1026	2540	2317	630
22	5513	0	240	2478	0	13109	1098	62	5753	1852	138	38	6890	1683	1137	2540	2642	660
23	5584	0	240	2478	0	13109	1098	63	5824	1859	71	7	6955	1616	1131	2540	2642	690
24	5726	0	240	2478	0	13109	1234	63	5966	1874	142	15	7080	1561	1114	2540	2967	720
25	5872	0	240	2478	0	13109	1234	66	6112	1890	146	16	7080	1512	968	2540	2967	750
26	6199	0	250	2478	0	13109	1370	69	6449	1931	337	41	7167	1485	718	2540	3292	780
27	6253	0	250	2478	0	13109	1370	71	6503	1936	54	5	7167	1434	664	2540	3292	810
28	6395	0	250	2478	0	13109	1506	71	6645	1951	142	15	7238	1393	593	2540	3617	840
29	6481	0	250	2478	0	13109	1506	74	6731	1961	86	10	7238	1352	507	2540	3617	870
30	6742	0	250	2478	0	13109	1642	76	6992	1988	261	27	7244	1325	252	2540	3942	900
31	6742	0	250	2478	0	13109	1642	76	6992	1988	0	0	7244	1282	252	2540	3942	930
32	6819	0	250	2478	0	13109	1778	81	7069	1996	77	8	7250	1247	181	2540	4267	960
33	6890	0	250	2478	0	13109	1778	84	7140	2004	71	8	7250	1214	110	2540	4267	990
34	6896	0	250	2478	0	13109	1914	88	7146	2004	6	0	7250	1178	104	2540	4592	1020
35	6896	0	250	2478	0	13109	1914	90	7146	2004	0	0	7250	1145	104	2540	4592	1050
36	6967	0	250	2478	0	13109	2050	93	7217	2012	71	8	7250	1117	33	2540	4917	1080
37	6967	0	250	2478	0	13109	2050	94	7217	2012	0	0	7250	1087	33	2540	4917	1110
38	6967	0	250	2478	0	13109	2186	94	7217	2012	0	0	7250	1058	33	2540	5242	1140
39	6967	0	250	2478	0	13109	2186	95	7217	2012	0	0	7250	1031	33	2540	5242	1170
40	6967	0	250	2478	0	13109	2322	95	7217	2012	0	0	7250	1006	33	2540	5567	1200
41	6967	0	250	2478	0	13109	2322	96	7217	2012	0	0	7250	981	33	2540	5567	1230
42	6967	0	250	2478	0	13109	2458	96	7217	2012	0	0	7250	958	33	2540	5892	1260
43	6967	0	250	2478	0	13109	2458	96	7217	2012	0	0	7250	935	33	2540	5892	1290
44	6967	0	250	2478	0	13109	2594	96	7217	2012	0	0	7250	914	33	2540	6217	1320
45	6967	0	250	2478	0	13109	2594	96	7217	2012	0	0	7250	894	33	2540	6217	1350
46	6967	0	250	2478	0	13109	2730	96	7217	2012	0	0	7250	874	33	2540	6542	1380
47	6967	0	250	2478	0	13109	2730	96	7217	2012	0	0	7250	856	33	2540	6542	1410
48	6967	0	250	2478	0	13109	2866	96	7217	2012	0	0	7250	838	33	2540	6867	1440
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TIME HISTORY OF DELIVERIES, TYPE 1 CRAFT

MATRIX HALFWORD SAVEVALUE 6

ROW	Deliveries: Type 1 Pallets	Type 2 Pallets	Type 3 Pallets	Vehicles	LVTs	Personnel	Total Force Effectiveness	Craft in Total	Total Pallets	Tons (10s)	Pallets in last 30 Min.	Tons in Last 30 Min.	Pallets Off-Loaded	Tons Per Hour	Pallets on Craft	Vehicles Off-Loaded	No. of Trips	Time in Mins.
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
2	0	0	0	66	0	330	0	0	0	30	0	30	0	300	0	103	4	60
3	0	0	0	93	0	465	0	2	0	42	0	12	0	280	0	140	50	90
4	0	0	0	104	0	500	1	0	0	47	0	5	0	235	0	183	58	120
5	0	0	0	171	0	725	1	0	0	76	0	29	0	304	0	187	74	150
6	0	0	0	172	0	730	2	0	0	77	0	1	0	256	0	216	110	180
7	0	0	0	189	0	775	2	0	0	84	0	7	0	240	0	250	113	210
8	0	0	0	238	0	875	4	0	0	105	0	21	132	262	132	253	131	240
9	0	0	0	247	0	900	4	3	0	109	0	4	330	242	330	277	163	270
10	0	0	0	256	0	925	6	0	0	113	0	4	495	226	495	300	166	300
11	0	0	0	293	0	950	6	0	0	128	0	15	594	232	594	300	178	330
12	99	0	0	293	0	950	9	2	99	138	99	10	924	230	825	300	200	360
13	297	0	0	294	0	950	9	20	297	160	198	22	924	246	627	300	207	390
14	462	0	0	294	0	950	12	24	462	177	165	17	924	252	462	300	216	420
15	561	0	0	294	0	950	12	31	561	188	99	11	924	250	363	300	221	450
16	891	0	0	295	0	950	15	39	891	223	330	35	924	278	33	300	227	480
17	891	0	0	295	0	950	15	46	891	223	0	0	924	262	33	300	238	510
18	891	0	0	295	0	950	18	50	891	223	0	0	924	247	33	300	238	540
19	891	0	0	295	0	950	18	61	891	223	0	0	924	234	33	300	238	570
20	891	0	0	295	0	950	21	62	891	223	0	0	924	223	33	300	238	600
21	891	0	0	295	0	950	21	63	891	223	0	0	924	212	33	300	239	630
22	891	0	0	295	0	950	24	61	891	223	0	0	961	202	70	300	239	660
23	891	0	0	295	0	950	24	61	891	223	0	0	961	193	70	300	239	690
24	891	0	0	295	0	950	27	61	891	223	0	0	961	185	70	300	239	720
25	895	0	0	295	0	950	27	61	895	224	4	1	961	179	66	300	239	750
26	928	0	0	295	0	950	30	62	928	227	33	3	961	174	33	300	240	780
27	928	0	0	295	0	950	30	62	928	227	0	0	961	168	33	300	241	810
28	928	0	0	295	0	950	33	62	928	227	0	0	961	162	33	300	241	840
29	928	0	0	295	0	950	33	63	928	227	0	0	961	156	33	300	241	870
30	928	0	0	295	0	950	36	64	928	227	0	0	961	151	33	300	241	900
31	928	0	0	295	0	950	36	64	928	227	0	0	961	146	33	300	241	930
32	928	0	0	295	0	950	39	64	928	227	0	0	961	141	33	300	241	960
33	928	0	0	295	0	950	39	64	928	227	0	0	961	137	33	300	241	990
34	928	0	0	295	0	950	42	64	928	227	0	0	961	133	33	300	241	1020
35	928	0	0	295	0	950	42	64	928	227	0	0	961	129	33	300	241	1050
36	928	0	0	295	0	950	45	64	928	227	0	0	961	126	33	300	241	1080
37	928	0	0	295	0	950	45	64	928	227	0	0	961	122	33	300	241	1110
38	928	0	0	295	0	950	48	64	928	227	0	0	961	119	33	300	241	1140
39	928	0	0	295	0	950	48	64	928	227	0	0	961	116	33	300	241	1170
40	928	0	0	295	0	950	51	64	928	227	0	0	961	113	33	300	241	1200
41	928	0	0	295	0	950	51	64	928	227	0	0	961	110	33	300	241	1230
42	928	0	0	295	0	950	54	64	928	227	0	0	961	108	33	300	241	1260
43	928	0	0	295	0	950	54	64	928	227	0	0	961	105	33	300	241	1290
44	928	0	0	295	0	950	57	64	928	227	0	0	961	103	33	300	241	1320
45	928	0	0	295	0	950	57	64	928	227	0	0	961	100	33	300	241	1350
46	928	0	0	295	0	950	60	64	928	227	0	0	961	98	33	300	241	1380
47	928	0	0	295	0	950	60	64	928	227	0	0	961	96	33	300	241	1410
48	928	0	0	295	0	950	63	64	928	227	0	0	961	94	33	300	241	1440
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TIME HISTORY OF DELIVERIES, TYPE 3 CRAFT

MATRIX HALFWORD SAVEVALUE 8

ROW	Deliveries Type 1 Pallets	Type 2 Pallets	Type 3 Pallets	Vehicles	LVTs	Personnel	Total Force Effectiveness	Craft in Total	Total Pallets	Tons (10s)	Pallets in Last 30 Min.	Tons in Last 30 Min.	Pallets Off-Loaded	Tons Per Hour	Pallets on Craft	Vehicles Off-Loaded	No. of Trips	Time in Mins.
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
2	0	0	0	314	0	1570	5	0	0	137	0	137	0	1370	0	495	0	60
3	0	0	0	382	0	1910	5	0	0	166	0	29	0	1106	0	723	22	90
4	0	0	0	382	0	1910	12	0	0	166	0	0	0	830	0	797	23	120
5	0	0	0	678	0	2975	12	0	0	291	0	125	0	1164	0	797	32	150
6	0	0	0	699	0	3080	34	0	0	300	0	9	0	1000	0	899	44	180
7	0	0	0	713	0	3150	34	0	0	306	0	6	40	874	40	985	48	210
8	0	0	0	839	0	3950	67	0	0	363	0	57	111	907	111	997	49	240
9	0	0	0	902	0	4355	67	1	0	392	0	29	123	871	123	1022	66	270
10	0	0	0	943	0	4500	109	0	0	409	0	17	187	818	187	1123	70	300
11	0	0	0	1017	0	5550	109	0	0	449	0	40	267	816	267	1123	75	330
12	0	0	0	1054	0	5840	171	0	0	466	0	17	267	776	267	1123	85	360
13	0	0	0	1067	0	5840	171	10	0	471	0	5	375	724	375	1123	88	390
14	0	0	0	1067	0	6090	236	6	0	474	0	3	531	677	531	1123	89	420
15	91	0	20	1067	0	6090	236	4	111	497	111	23	673	662	562	1123	90	450
16	91	0	21	1067	0	6090	301	5	112	497	1	0	673	621	561	1123	93	480
17	91	0	33	1067	0	6090	301	4	124	505	12	8	886	594	762	1123	94	510
18	121	0	87	1067	0	6090	366	2	208	543	84	38	1099	603	891	1123	96	540
19	151	0	117	1067	0	6090	366	2	268	565	60	22	1241	594	973	1123	100	570
20	239	0	137	1067	0	6090	431	1	376	587	108	22	1312	587	936	1123	103	600
21	310	0	137	1067	0	6090	431	0	447	595	71	8	1437	566	990	1123	105	630
22	401	0	181	1067	0	6090	496	1	582	633	135	38	1649	575	1067	1123	109	660
23	472	0	181	1067	0	6090	496	2	653	640	71	7	1714	556	1061	1123	111	690
24	614	0	181	1067	0	6090	561	2	795	655	142	15	1839	545	1044	1123	112	720
25	756	0	181	1067	0	6090	561	5	937	670	142	15	1839	536	902	1123	114	750
26	1050	0	191	1067	0	6090	626	7	1241	708	304	38	1926	544	685	1123	118	780
27	1104	0	191	1067	0	6090	626	9	1295	713	54	5	1926	528	631	1123	122	810
28	1246	0	191	1067	0	6090	691	9	1437	728	142	15	1997	520	560	1123	125	840
29	1332	0	191	1067	0	6090	691	11	1523	737	86	9	1997	508	474	1123	126	870
30	1593	0	191	1067	0	6090	756	12	1784	765	261	28	2003	510	219	1123	130	900
31	1593	0	191	1067	0	6090	756	12	1784	765	0	0	2003	493	219	1123	132	930
32	1670	0	191	1067	0	6090	821	17	1861	773	77	8	2009	483	148	1123	133	960
33	1741	0	191	1067	0	6090	821	20	1932	780	71	7	2009	472	77	1123	134	990
34	1747	0	191	1067	0	6090	886	24	1938	781	6	1	2009	459	71	1123	135	1020
35	1747	0	191	1067	0	6090	886	26	1938	781	0	0	2009	446	71	1123	136	1050
36	1818	0	191	1067	0	6090	951	29	2009	789	71	8	2009	438	0	1123	137	1080
37	1818	0	191	1067	0	6090	951	30	2009	789	0	0	2009	426	0	1123	137	1110
38	1818	0	191	1067	0	6090	1016	30	2009	789	0	0	2009	415	0	1123	137	1140
39	1818	0	191	1067	0	6090	1016	31	2009	789	0	0	2009	404	0	1123	137	1170
40	1818	0	191	1067	0	6090	1081	31	2009	789	0	0	2009	394	0	1123	137	1200
41	1818	0	191	1067	0	6090	1081	32	2009	789	0	0	2009	384	0	1123	137	1230
42	1818	0	191	1067	0	6090	1146	32	2009	789	0	0	2009	375	0	1123	137	1260
43	1818	0	191	1067	0	6090	1146	32	2009	789	0	0	2009	366	0	1123	137	1290
44	1818	0	191	1067	0	6090	1211	32	2009	789	0	0	2009	358	0	1123	137	1320
45	1818	0	191	1067	0	6090	1211	32	2009	789	0	0	2009	350	0	1123	137	1350
46	1818	0	191	1067	0	6090	1276	32	2009	789	0	0	2009	343	0	1123	137	1380
47	1818	0	191	1067	0	6090	1276	32	2009	789	0	0	2009	335	0	1123	137	1410
48	1818	0	191	1067	0	6090	1341	32	2009	789	0	0	2009	328	0	1123	137	1440
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TIME OF DELIVERY INLAND BY HELICOPTERS

MATRIX HALFWORD SAVEVALUE 31

	Deliveries Type 1 Pallets	Type 2 Pallets	Type 3 Pallets	Vehicles	LVTs	Personnel	Total Force Effectiveness	Craft in Total	Total Pallets	Tons (10s)	Pallets in Past 30 Min.	Tons in Last 30 Min.	Pallets off-Loaded	Tons Per Hour	Pallets on Craft	Vehicles off-Loaded	No. of Trips	Time in Mins.
ROW 1	0	0	0	13	0	2321	0	18	0	33	0	0	0	0	0	0	86	30
2	0	0	0	73	0	4028	3	21	0	77	0	44	0	770	0	178	212	60
3	0	0	0	199	0	4726	3	14	0	136	0	59	0	906	0	301	335	90
4	0	0	0	329	0	5277	20	3	0	194	0	58	0	970	0	435	456	120
5	0	0	0	462	0	5719	20	0	0	253	0	59	0	1012	0	575	569	150
6	0	0	0	589	0	5886	55	1	0	306	0	53	0	1020	0	711	677	180
7	0	0	0	737	0	6032	55	0	0	367	0	61	135	1048	135	832	792	210
8	174	0	0	844	0	6042	106	0	174	428	174	61	375	1070	201	952	891	240
9	408	0	0	961	0	6042	106	0	408	499	234	71	714	1108	306	1057	1004	270
10	783	0	0	1063	0	6042	170	5	783	579	375	80	1365	1158	582	1109	1113	300
11	1449	0	0	1112	0	6052	170	1	1449	669	666	90	2226	1216	777	1117	1217	330
12	2364	0	0	1115	0	6069	238	0	2364	765	915	96	3039	1275	675	1117	1307	360
13	3144	0	0	1116	0	6069	238	0	3144	846	780	81	3801	1301	657	1117	1393	390
14	3846	0	24	1116	0	6069	306	24	3870	934	726	88	4274	1334	404	1117	1483	420
15	4197	0	58	1116	0	6069	306	104	4255	992	385	58	4280	1322	25	1117	1536	450
16	4197	0	59	1116	0	6069	374	127	4256	993	1	1	4280	1241	24	1117	1539	480
17	4215	0	59	1116	0	6069	374	127	4274	995	18	2	4280	1170	6	1117	1541	510
18	4215	0	59	1116	0	6069	442	128	4274	995	0	0	4280	1105	6	1117	1541	540
19	4215	0	59	1116	0	6069	442	129	4274	995	0	0	4280	1047	6	1117	1541	570
20	4218	0	59	1116	0	6069	510	130	4277	995	3	0	4280	995	3	1117	1542	600
21	4218	0	59	1116	0	6069	510	130	4277	995	0	0	4280	947	3	1117	1542	630
22	4221	0	59	1116	0	6069	578	130	4280	995	3	0	4280	904	0	1117	1543	660
23	4221	0	59	1116	0	6069	578	131	4280	995	0	0	4280	865	0	1117	1544	690
24	4221	0	59	1116	0	6069	646	131	4280	995	0	0	4280	829	0	1117	1544	720
25	4221	0	59	1116	0	6069	646	131	4280	995	0	0	4280	796	0	1117	1544	750
26	4221	0	59	1116	0	6069	714	131	4280	995	0	0	4280	765	0	1117	1544	780
27	4221	0	59	1116	0	6069	714	132	4280	995	0	0	4280	737	0	1117	1544	810
28	4221	0	59	1116	0	6069	782	132	4280	995	0	0	4280	710	0	1117	1544	840
29	4221	0	59	1116	0	6069	782	132	4280	995	0	0	4280	686	0	1117	1544	870
30	4221	0	59	1116	0	6069	850	133	4280	995	0	0	4280	663	0	1117	1544	900
31	4221	0	59	1116	0	6069	850	133	4280	995	0	0	4280	641	0	1117	1544	930
32	4221	0	59	1116	0	6069	918	133	4280	995	0	0	4280	621	0	1117	1544	960
33	4221	0	59	1116	0	6069	918	133	4280	995	0	0	4280	603	0	1117	1544	990
34	4221	0	59	1116	0	6069	986	133	4280	995	0	0	4280	585	0	1117	1544	1020
35	4221	0	59	1116	0	6069	986	133	4280	995	0	0	4280	568	0	1117	1544	1050
36	4221	0	59	1116	0	6069	1054	133	4280	995	0	0	4280	552	0	1117	1544	1080
37	4221	0	59	1116	0	6069	1054	133	4280	995	0	0	4280	537	0	1117	1544	1110
38	4221	0	59	1116	0	6069	1122	133	4280	995	0	0	4280	523	0	1117	1544	1140
39	4221	0	59	1116	0	6069	1122	133	4280	995	0	0	4280	510	0	1117	1544	1170
40	4221	0	59	1116	0	6069	1190	133	4280	995	0	0	4280	497	0	1117	1544	1200
41	4221	0	59	1116	0	6069	1190	133	4280	995	0	0	4280	485	0	1117	1544	1230
42	4221	0	59	1116	0	6069	1258	133	4280	995	0	0	4280	473	0	1117	1544	1260
43	4221	0	59	1116	0	6069	1258	133	4280	995	0	0	4280	462	0	1117	1544	1290
44	4221	0	59	1116	0	6069	1326	133	4280	995	0	0	4280	452	0	1117	1544	1320
45	4221	0	59	1116	0	6069	1326	133	4280	995	0	0	4280	442	0	1117	1544	1350
46	4221	0	59	1116	0	6069	1394	133	4280	995	0	0	4280	432	0	1117	1544	1380
47	4221	0	59	1116	0	6069	1394	133	4280	995	0	0	4280	423	0	1117	1544	1410
48	4221	0	59	1116	0	6069	1462	133	4280	995	0	0	4280	414	0	1117	1544	1440
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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